Chapter 5
The Science and Effectiveness of Wetland Management Tools

5.1 Reader's Guide to this Chapter

This chapter builds on the previous discussion of how wetlands function (Chapter 2), how human activities and changes in land use cause disturbances (across the landscape and at specific sites) that influence the factors that control wetland functions (Chapter 3), and how wetland functions are impacted by these disturbances (Chapter 4).

Chapter 5 presents a synthesis of what the current literature reports on four tools currently used to address impacts to wetlands and their functions: wetland definitions, wetland delineation methods, wetland ratings, and buffers. This chapter does not provide language or recommendations for regulatory or policy language—those will be provided in a separate volume on management options and recommendations (Volume 2).

5.1.1 Chapter Contents

Major sections of this chapter and the topics they cover include:

Section 5.2, Introduction and Background on Regulatory Tools introduces the key wetland management tools that are discussed in this chapter.

Section 5.3, How Wetlands Are Defined and Delineated describes similarities and differences in the way various agencies define what a wetland is. It explains the critical difference between *biological wetlands* and *regulated wetlands* and discusses certain types of wetlands that are frequently exempted from regulation such as isolated wetlands, small wetlands, or those designated as Prior Converted wetlands. The various manuals that have been developed to guide the delineation of wetland boundaries are then briefly discussed.

Section 5.4, Wetland Rating Systems discusses how rating systems have been developed to rapidly assess wetland characteristics in the field. These characterizations allow wetlands to be rated for regulatory or management purposes. The section introduces the reader to the Washington State Wetland Rating System, which was briefly mentioned previously in a number of places in the document. It also includes discussion of certain wetland types that are singled out for special attention under the Washington State rating system.

Section 5.5, Buffers comprises the bulk of this chapter. This section provides a synthesis of the literature on how buffers protect and maintain wetland functions. The section concludes by summarizing recommendations from the literature for establishing effective buffer widths.

Section 5.6, Chapter Summary and Conclusions ties together the major concepts presented in the chapter.

5.1.2 Where to Find Summary Information and Conclusions

Each major section of this chapter concludes with a brief summary of the major points resulting from the literature review on that topic in a bulleted list. The reader is encouraged to remember that a review of the entire section preceding the summary is necessary for an in-depth understanding of the topic.

For summaries of the information presented in this chapter, see the following sections:

- Section 5.3.6
- Section 5.4.2
- Section 5.5.3.5
- Section 5.5.4.4
- Section 5.5.5.4
- Section 5.5.6.1

In addition, Section 5.6 provides a summary and conclusions about the overarching themes gleaned from the literature and presented in this chapter.

5.1.3 Data Sources and Data Gaps

No literature review was conducted for the section on wetland definitions or delineations. Both of these management tools are currently established by state and federal statutes, and it was determined that review of the previous discourse on those topics was not relevant to the current state of the science for Washington State. Several synthesis documents on small and isolated wetlands have been published since 2000. Considerable research was published prior to 2000, focused on the role of small wetlands relative to wildlife in a landscape context.

Papers on the adequacy or effectiveness of wetland rating systems were not found; instead the literature focuses on function assessment methods. This chapter does not attempt to assess the science on wetland function assessment because the Washington Department of Ecology has completed function assessment methods for several different wetland hydrogeomorphic types on both sides of the state within the last five years (see Chapter 2 for further information).

The subject of buffers is well documented in the scientific literature. Literature related to agricultural practices and vegetated filter strips from the north-central United States and south-central Canada is relevant to some agricultural practices in Washington, especially in areas east of the Cascades. Studies on buffers in urban and suburban settings conducted in the Pacific Northwest are also relevant.

The majority of research on buffers tends to focus on how buffers influence water quality. Far fewer studies examine the influence of a buffer's physical characteristics on attenuating rates of surface water flow.

Most studies on buffers related to wildlife document the needs of a particular species or guild related to how far they travel from aquatic habitats to fulfill their life-histories. While there is substantial literature on the implications of habitat fragmentation and connectivity, this literature does not specifically address the role of buffers in providing connectivity between wetlands and other parts of the landscape.

Numerous compilations and syntheses of "buffer" literature have been completed since 1990. These synthesis documents are used in this report as direct sources when no more recent research was found. This chapter also cites literature related to stream buffers and riparian areas when the findings are relevant to the functions or processes these areas provide to the adjacent aquatic resource.

A more detailed description of the types of literature used and any recognized gaps in the scientific literature is provided within each section on buffers as appropriate.

5.2 Introduction and Background on Regulatory Tools

The regulatory tools discussed in this chapter are components of "typical" wetland protection programs. The intent is not to analyze all elements of protection programs and their regulations but to focus on the key science-based elements relating directly to wetland protection and management. Therefore, this chapter focuses on the following four elements:

- Wetland definitions
- Wetland delineation methods
- Wetland ratings
- Buffers

The topic of compensatory mitigation, another key regulatory tool, is discussed separately in Chapter 6 because of the volume of information and literature available on this subject.

5.3 How Wetlands are Defined and Delineated

5.3.1 How Agencies Define Wetlands

Several definitions of wetlands have been developed and used by various federal, state, and local agencies and jurisdictions. The effectiveness of current federal or state wetland definitions was not evaluated as part of this report. However, definitions are included here because how a wetland is defined is critical to determining what areas are subject to the provisions of a law or regulation.

For the purposes of most laws and regulations, wetlands are usually defined using one of the following two definitions:

> *Those areas that are saturated or inundated by surface or groundwater at a frequency and duration sufficient to support, and under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas.* (U.S. Army Corps of Engineers 1987); or
>
> *"Wetlands" or "wetland areas" means areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs and similar areas. Wetlands do not include those artificial wetlands intentionally created from non-wetland sites, including, but not limited to, irrigation and drainage ditches, grass-lined swales, canals, detention facilities, wastewater treatment facilities, farm ponds, and landscape amenities, or those wetlands created after July 1, 1990, that were unintentionally created as a result of the construction of a road, street, or highway. Wetlands may include those artificial wetlands intentionally created from nonwetland areas to mitigate the conversion of wetlands.* (Washington Administrative Code 173-22-030.)

The Washington State definition is derived from the U.S. Army Corps of Engineers definition, but it also includes clarifying language that identifies which common human-made or induced features are not meant to be defined as wetland. The state definition is required by the Growth Management Act (RCW 36.70A.030 (20)) to be used in all local critical area regulations.

In addition, for the process of conducting the National Wetland Inventory, the U.S. Fish and Wildlife Service (USFWS) defined wetlands as follows:

> *Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. For the purpose of this classification wetlands must have one or more of the following three attributes: (1) at least periodically, the land supports predominantly hydrophytes, (2) the substrate is predominantly undrained hydric soil, and (3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of each year.* (Cowardin et al. 1979.)

Note that the definition used by the USFWS allows the use of a single parameter to determine if an area is a wetland. The definition also includes areas that may not be vegetated such as gravel bars and mudflats. The Corps of Engineers and Ecology definitions require the presence of all three parameters (vegetation, soil, and hydrology) for an area to be considered a wetland, and they both assume that wetlands generally are vegetated.

5.3.2 Biological vs. Regulated Wetlands

In some jurisdictions, all lands that meet the definition of “wetland” are regulated. However, it is not unusual for a jurisdiction to differentiate within its regulations between “wetlands” (i.e., biological wetlands) and “regulated wetlands” (i.e., wetlands that they intend to regulate). The definition of what constitutes a regulated wetland may vary from jurisdiction to jurisdiction.

In reviewing regulatory language from local wetland regulations, the three primary criteria used to differentiate between “wetland” and “regulated wetland” were:

- The category or rating of the wetland
- The size of the wetland
- Wetland types such as Prior Converted croplands and isolated wetlands

In general, a category or rating system has been historically used in regulatory language to differentiate between wetlands that need different degrees of protection. Rating systems are used by local jurisdictions to group wetlands based on physical characteristics and/or functions that the wetlands may provide and how those characteristics or functions are valued. Section 5.4 of this document describes the current state of the science on wetland ratings and the Washington State Wetland Rating System for eastern and western Washington.

The criterion of wetland size is usually a minimum below which the jurisdiction will not regulate a wetland. For example, the jurisdiction may allow no fill in wetlands larger than 10,000 square feet, or they may include language such as “Category 2 wetlands larger than 0.25 acre cannot be altered." The historical rationale for the use of size as a regulatory criterion was the perception that "bigger is better" and the belief that small wetlands were less important and did not provide significant functions. The scientific literature of the last 10 years has made it clear that size does matter, but not in the way previously believed. Small wetlands have been shown in multiple studies to contain a significant diversity of plant and animal species. (See Section 5.3.3 for more information.)

Additionally, two other wetland types may be exempted from regulation: isolated wetlands and "Prior Converted" wetlands.

A U.S. Supreme Court decision in 2001 determined that most isolated wetlands are not subject to regulation under Section 404 of the federal Clean Water Act. However, the Court did not define "isolated," and the federal government has not issued any new guidance or regulations to clarify the situation. In general practice, the U.S. Army Corps of Engineers, the federal agency that administers the Clean Water Act, is considering isolated wetlands to be those of any size that have no direct surface water connection to any navigable waters. Washington State has determined that isolated wetlands are regulated by the Department of Ecology under the state Water Pollution Control Act (RCW 90.48). Since some local jurisdictions in Washington fashion their wetland regulations on the federal or state standards, it is important to consider the implications of not regulating isolated wetlands. Thus, scientific information on isolated wetlands is discussed in Section 5.3.4.

Prior Converted wetlands (or Prior Converted croplands) are another type of wetlands that are exempt from regulation by the federal government. Prior Converted wetlands are those wetlands that were drained or otherwise manipulated prior to December 23, 1985, for the production of commodity crops where inundation (ponding) does not occur for more than 14 consecutive days during the growing season. However, most of these areas still meet the three criteria for being a biological wetland. As with isolated wetlands, the Department of Ecology regulates Prior Converted wetlands under state law.

No information on areas meeting the definition of Prior Converted wetland (or cropland) was found in the scientific literature. However, many wetlands meeting these criteria would still be providing important functions given that the criteria for being designated "Prior Converted" require only that the wetland has been manipulated for production of commodity crops prior to 1985 and does not pond for more than 14 consecutive days during the growing season. If the agricultural activities were abandoned, the area could revert to a plant community characteristic of wetlands and, without maintenance of the hydrologic modifications, the wetland's water regime may revert to a condition more like that which existed prior to the alteration. Even if they have been maintained for agricultural production, many Prior Converted wetlands in western Washington pond during the winter and provide significant overwintering habitat for waterfowl (Zeigler, personal communication). Prior Converted wetlands may also provide important flood storage functions. Further analysis of the functions of areas designated as Prior Converted wetlands is needed.

No literature was found that discussed the ecological consequences of the legal bifurcation between biological wetlands and regulated wetlands. However, literature was found that discusses the functions and values provided by small wetlands and isolated wetlands, as discussed below.

5.3.3 Small Wetlands

The elimination of small wetlands is an issue that has gained increased attention over the past 10 years. Many regulations have preferentially allowed for filling of small wetlands because size is one of the most common characteristics used in determining wetland ratings at the local level. Smaller wetlands typically receive lower levels of protection. And yet, the loss of small wetlands is one of the most common cumulative impacts on wetlands and wildlife (Weller 1988, Tiner 2002).

In addition to the obvious loss of habitat for wildlife, fragmentation of habitat increases as small wetlands are removed, resulting in greater distances between wetland patches in the landscape. Semlitsch and Bodie (1998) found that creating greater distances between wetlands can have a significant effect on the ability of a landscape to support viable populations of amphibians, as juveniles dispersing from a source wetland may not be able to travel far enough to recolonize other surrounding (now distant) wetlands. Management priorities have focused on larger, semi-permanent wetlands, with the least emphasis on protecting the smaller, seasonal wetlands that are critical components of wetland complexes (Naugle et al. 2001).

This section describes studies of the use of small wetlands by wildlife and the role that small wetlands play in maintaining habitat connectivity. Studies of the relationship between wetland size and wildlife distribution have mostly focused on amphibians and birds. Few studies have examined how mammal use of wetlands relates to wetland size, and no studies of this relationship were found for macroinvertebrates or reptiles. No studies were found that documented the role that small wetlands play in providing water quality or hydrologic functions.

Small wetlands are differentiated only by their size. No definition of "small" is provided here because size is defined variously in scientific studies and by local regulatory or policy language. Small wetlands can have outlets, they can be in a floodplain, or they can be otherwise associated with a larger aquatic system.

Moler and Franz (1987) describe small wetlands as follows:

> *To a great extent, the unique values and functions of small, isolated wetlands have been overlooked. This oversight derives from several factors, perhaps foremost being the general tendency to think of small wetlands as being little more than subsets of larger wetlands. So long as the uniqueness of small wetlands is unrecognized, then it is intuitive to think of wetlands as declining in value directly as function of size. Similarly, so long as the unique values of isolated wetlands are unrecognized, it is understandable that connected wetlands might be*

> *considered of greater value. In reality, small isolated wetlands are biologically unique systems. Because of their isolation and small size, they support a very different assemblage of species than that found in larger, more permanently wet situations. The ephemeral nature of many small wetlands makes them unsuitable for species which require permanent water.*

5.3.3.1 Amphibians and Small Wetlands

Snodgrass et al. (2000) undertook a study of amphibian use of wetlands to address three commonly held beliefs about small wetlands:

- They have short hydroperiods
- They support few species
- They support species that are also found in larger wetlands

Snodgrass et al. (2000) determined that amphibian species richness increases with length of hydroperiod. They also concluded that short-hydroperiod wetlands (smaller temporarily ponded wetlands) are also important in maintaining biological diversity in that they support species not found in larger wetlands with longer hydroperiods. The species they found in small wetlands were not a subset of those in larger wetlands but rather a unique group of species.

Similarly, amphibian richness in Puget Sound wetlands was found to have no correlation with wetland size. High richness occurred in some of the smallest wetlands (Richter and Azous 1995). The study indicates that small wetlands that are vegetatively simple can serve adequately as breeding habitats as long as favorable nonbreeding habitat is present nearby. Species richness also was not related to persistence of ponding.

Gibbs (1993) conducted a simulation model in Maine from which she theorized that small wetlands may be most important for wetland organisms with low population growth rates and low densities. The model demonstrated that the loss of small freshwater wetlands (less than approximately 5 acres [2 ha]) would result in a decline of total wetland area by 19% and total wetland number by 62%, while the average distance between wetlands would increase by 67% (Gibbs 1993). The model showed that the loss of small wetlands would result in a change (from 90% to 54%) of the area that would lie within the maximum migration distance of terrestrial-dwelling and aquatic-breeding amphibians. The risk of extinction would significantly increase for local populations of turtles, small birds, and small mammals that are currently stable even though the model showed no change in the risk of metapopulation extinction for salamanders or frogs. Amphibian populations in the study were buffered from the risk of extinction due to high rates of population increase. The model demonstrated that dispersal ability for amphibians is a predictor of population growth rate and density, not sensitivity of a population to loss of small wetlands.

5.3.3.2 Birds and Small Wetlands

Bird use of wetlands appears to have a stronger relationship to wetland size than that of amphibians. Bird richness was positively correlated with larger wetland size in a Puget Sound study of palustrine wetlands (Richter and Azous 2001b). This is attributed to the fact that larger wetlands in the study generally had greater structural complexity and a greater number of habitat types.

Martin-Yanny (1992) also found that bird species richness and abundance in wetlands of the Pacific Northwest are positively correlated with wetland size. However, they noted that habitat heterogeneity was a more important determining factor than wetland area in influencing bird species richness. Wetlands in highly urbanized watersheds had fewer neotropical migrant species, fewer ground-nesting birds, and more edge-tolerant (habitat generalist) species. This is because urbanizing watersheds tend to have smaller wetlands (less than 10 acres [4 ha]) with more edge habitat, making birds more susceptible to competition, predation, and nest parasitism. The author recommends preserving large wetlands or complexes of smaller wetlands that are connected by extensive upland buffers.

In northern prairie marshes, bird species richness was also seen to increase with marsh size and to decrease as the wetland became more isolated (Brown and Dinsmore 1986). Marshes that were part of wetland complexes showed higher species richness than isolated wetlands. Certain bird species used smaller marshes only when the marshes were part of a wetland complex. Large isolated marshes in the study often had lower species richness than smaller marshes that were part of wetland complexes. While bird species richness increased, the rate of increase slowed as the marshes became larger. In other words, they concluded that prairie marshes in the size range of 49 to 74 acres (20 to 30 ha) were more efficient in preserving bird species than larger marshes.

A study of agriculturally disturbed wetlands in western Oregon reached similar conclusions in finding that larger wetlands support more bird species (Budeau and Snow 1992). These authors also showed that wetlands of all sizes were important to water-birds.

However, in eastern Washington, Foster et al. (1984) found that waterfowl breeding use of wetlands in the Columbia Basin was greatest in smaller wetlands (less than 1 acre [0.4 ha]).

5.3.3.3 Mammals and Small Wetlands

The study that modeled the effects of the loss of small wetlands in Maine showed that local populations of small mammals faced a significant risk of extinction following the loss of small wetlands (Gibbs 1993). However, in a study of Puget Sound wetlands, Richter and Azous (2001c) concluded that wetland size alone was not a significant factor in determining mammal richness or abundance. They noted that small-mammal richness was most closely affected by the combined factors of:

- Wetland size
- Extent of retention of forest adjacent to the wetland
- Quantity of large woody debris within wetland buffers

5.3.4 Isolated Wetlands

Isolated wetlands are being addressed in this document because of the recent Supreme Court decision to exclude many isolated wetlands from federal regulation. This decision was made based on a legal interpretation of jurisdiction under the federal Clean Water Act. The key factor was the language in the Act that relates to navigable waters. The Court did not rule that isolated wetlands are less important than non-isolated wetlands, only that the intent of Congress in passing the Clean Water Act was to relate the protection of waters of the United States to navigability. The Court also did not provide any definition of what constitutes "isolation" for purposes of jurisdiction.

Much confusion has resulted from this decision and some statements have been made that isolated wetlands are less important or less worthy of protection. This section briefly summarizes some of the basic science on isolated wetlands, drawing heavily from the work of Tiner et al. (2002) who summarized much of the science on isolated wetlands. Readers are directed to this work for more detailed information. Additionally, the work of Hruby et al. (1999) in developing assessment methods for wetland functions in Washington provides important scientific information on depressional closed wetlands, a wetland type that constitutes the majority of isolated wetlands in Washington.

Wetlands can be defined as isolated based on their geographic isolation, ecological isolation, or hydrologic isolation (Tiner et al. 2002). For this discussion, isolated wetlands are defined by their hydrologic isolation—they do not have a surface outlet, even seasonally, to another water body. Although frequently described as closed depressions (Tiner et al. 2002), isolated wetlands can also be sloped wetlands where surface water, if present, re-enters the shallow groundwater zone at the base of the wetland and is not linked via surface flows to a downstream water body. Isolated wetlands are not necessarily small. They can be large systems with substantial heterogeneity and diverse habitat types (Tiner et al. 2002).

Generally, isolated wetlands provide most of the same functions as non-isolated wetlands and do so for the same reasons: position in the landscape, hydrologic regime, and type of soils and vegetation present. Basic functions of isolated wetlands as described by Hruby et al. (1999) and Tiner et al. (2002) are presented below:

- **Water quantity.** Isolated wetlands have no surface outlet. Therefore their ability to retain surface water may be significant, depending upon the surrounding topography. This provides potential flood storage because no surface water leaves the wetland to cause potential flooding downgradient.

- **Water quality.** Because they lack an outlet, isolated wetlands function as sediment traps when sediment moves into them. Isolated wetlands function as sinks for most dissolved and all sediment-associated nutrients and toxics because they have no outlets that allow materials to be transported downgradient. Their ability to take up and transform nutrients and toxics is similar to non-isolated wetlands and is largely a function of vegetation type and cover.

- **Wildlife habitat.** Isolated wetlands provide wildlife habitat functions similar to those of non-isolated wetlands, except in regard to habitat for migrating fish. The assessment models for general habitat suitability for depressional closed wetlands (isolated) and depressional outflow wetlands (non-isolated) are the same (Hruby et al. 1999). The habitat value of isolated wetlands is governed by the same factors as non-isolated wetlands (hydrologic regime, vegetation, connectivity to other habitats, etc.). Tiner et al. (2002) found that isolated wetlands provide essential habitat for a wide range of guilds and may be vital to maintaining viable, genetically diverse metapopulations. They state:

  From an ecological standpoint, isolated wetlands are among the country's most significant biological resources. In some areas, isolation has led to the evolution of endemic species vital for the conservation of biodiversity. In other cases, their isolation and sheer numbers in a given locality have made these wetlands crucial habitats for amphibian breeding and survival (e.g., woodland vernal pools and cypress domes) or for waterfowl and waterbird breeding (e.g., potholes). In arid and semi-arid regions, many isolated wetlands are veritable oases – watering places and habitats vital to many wildlife that use them for breeding, feeding, and resting, or for their primary residence.

5.3.5 Delineation Methods

In addition to the definition of what constitutes a wetland, the U.S. Army Corps of Engineers and Ecology have provided guidance on how to determine the edge of a wetland (i.e., how to delineate the wetland boundary). Delineating a wetland's boundary is a necessary step in the regulatory process because it factors into calculations of potential wetland impacts and determines the starting point for buffers and setbacks.

The U.S. Army Corps of Engineers published two federal manuals to delineate wetlands, one in 1987 and another in 1989. In subsequent years (1991, 1992, and with EPA in 1994) they released updates to clarify questions and provide regional guidance.

In the early 1990s there was substantial controversy over proposals to change the 1987 and 1989 federal delineation manuals. A substantial amount of literature was produced analyzing the effectiveness of the various delineation manuals for determining a wetland edge. In subsequent years, the use of the 1987 Federal Manual for Delineation of Wetland Areas has become the required legal standard for the U.S. Army Corps of Engineers.

As required by state legislation, Ecology issued the *Washington State Wetlands Identification and Delineation Manual* in 1996 (WAC 173-22-080, Ecology publication #96-94). Ecology's manual uses the original 1987 Corps of Engineers manual and incorporates changes in the manual made by the federal government since 1987. The state manual includes national guidance issued by the Corps in 1991 and 1992 (which is not used in the 1987 Corps manual), as well as regional guidance issued by the Corps and EPA in 1994. In addition, the state manual eliminated references and examples that were not relevant to Washington State and added examples and situations relevant to Washington. The 1996 state manual is required by statute (RCW 36.70A.175) to be used by local jurisdictions in implementing the Growth Management Act. Since the two manuals rely upon the same criteria and indicators for hydrology, soils and vegetation, proper use of either manual should result in the same boundary.

5.3.6 Summary of Key Points

- Regulatory agencies define the term "wetland" in slightly different ways.
- Local jurisdictions often differentiate between biological wetlands and regulated wetlands. The distinction is often based on the wetland rating and/or wetland size.
- The studies of the correlation of wetland size to wildlife use conflict somewhat in their findings, but most generally conclude that small wetlands are important habitats (particularly where adjacent buffer habitats are available) and that elimination of small wetlands can negatively impact local populations.
- Small wetlands provide habitat for a range of species that are not a subset of the species found in larger, more permanently inundated wetlands. For example, small wetlands do not just provide a smaller area for the same array of amphibian species that can be found in larger wetlands.
- Small wetlands are very important in reducing isolation among wetland habitat patches. Smaller wetlands provide significant habitat for wildlife and affect the habitat suitability of larger wetlands by reducing isolation on the landscape.
- The presence of small wetlands reduces the distance between wetlands and thus increases the probability of successful dispersal of organisms. This, in turn, likely increases the number of individuals dispersing among patches in a wetland mosaic, thereby reducing the chance of population extinction.
- Isolated wetlands provide the same range of wetland functions as non-isolated wetlands. Isolated wetlands provide important water quantity, water quality, and habitat functions.
- The U.S. Army Corps of Engineers 1987 wetland delineation manual and the 1996 *Washington State Wetlands Identification and Delineation Manual* are the

current standards to be used in determining the boundary of a wetland. Correct use of these two manuals should result in the same wetland boundary.

5.4 Wetland Rating Systems

Wetland rating systems (or categorizations) are one of the numerous procedures that have been developed to analyze wetlands, providing ways to identify, characterize, or measure wetland characteristics, functions, and social benefits (values). Ratings, as well as other procedures such as function assessment, are used by natural resource managers and regulators in a variety of contexts for regulating, planning, and managing the wetland resource (Bartoldus 1999). In the context of local regulations, rating systems are used to categorize wetlands based on different needs for protection. However, rating systems can often be used as one means to analyze wetlands.

Many different procedures to analyze wetlands have been developed in the last three decades. These range from detailed scientific evaluations that may require many years to complete, to the judgments of individual experts during one visit to a wetland. For example, Bartoldus (1999) summarized 40 different tools that had been developed up to 1998 and that are used to meet the needs of regulating and managing wetlands.

Although many different rating-type tools have been developed, the literature search for this document did not uncover any analyses of the effectiveness of rating systems at protecting the wetland resource. It is assumed that better protection for wetlands is provided with improved understanding of wetland functions and values (e.g., Roth et al. 1993, National Research Council 1995).

Scientific rigor is often time consuming and costly. For regulatory use, tools are needed to provide some information on the functions and values of wetlands in a time- and cost-effective way. One way to accomplish this is with an analytical tool that categorize wetlands by their important attributes or characteristics based on the collective judgment of regional experts. Categorization methods, such as rating systems, are relatively rapid but can still provide some scientific rigor (Hruby 1999).

The rapid method most commonly used for analyzing wetlands in eastern and western Washington has been the *Washington State Wetland Rating System* (Ecology 1991, 1993, Hruby 2003). This rating system or some modification of it has been incorporated in the wetland regulations of at least 20 counties in the state and many cities and towns as well (Office of Community Development, personal communications).

> In the first edition of the *Washington State Wetland Rating System*, the term "rating" was not used in a manner that is consistent with its definition in the dictionary, and this has caused some confusion. The method does not rate the wetlands and generate a relative estimate of value (e.g., high, medium, low). Rather, it is a categorization of wetlands based on specific criteria such as sensitivity to disturbance and rarity in the landscape.

The rating system was designed to differentiate between wetlands based on their sensitivity to disturbance, their significance, their rarity, our ability to replace them, and the functions they provide. However, this rating system is not intended to replace a full assessment that may be necessary to determine the levels of performance for numerous functions or plan and monitor a compensatory mitigation project. As noted in the Washington State rating system:

> *The rating categories are intended to be used as the basis for developing standards for protecting and managing the wetlands to minimize further loss of their resource value. The management decisions that can be made based on the rating include the width of buffers necessary to protect the wetland from adjacent development, the ratios needed to compensate for impacts to the wetland, and permitted uses in the wetland* (Hruby 2003).

The rating system for both eastern and western Washington is being revised by Ecology in conjunction with teams of wetland experts and local planners in each region who are providing technical input and field testing. The rating system for eastern Washington will be finalized in fall 2003 and the western Washington rating system will be finalized by early 2004. The goal of the revisions is to reflect the best and most current science on wetlands and how they function (using three broad groups of functions—hydrologic, water quality, and habitat) while maintaining rapidity and ease of use. You can access the draft rating system for eastern Washington at the following web site: www.ecology.wa.gov/programs/sea/wetlan.html

Wetland rating systems used in other parts of the nation

Categorization systems have also been used in other parts of the United States to manage wetlands. Other states have wetland categorizations as part of their wetland laws and rules, and other jurisdictions have used them to help manage wetlands for specific projects. For example:

Vermont adopted a law (10 VSA Chapter 37, Section (a) (7-9)) mandating that rules be adopted to identify Vermont's significant wetlands. The rules categorize wetlands into three classes of which the first two are considered "significant" (Vermont Department of Environmental Conservation 1999).

New Jersey has a wetland categorization included directly in its law (NJAC 7:7A). Criteria are provided for categorizing wetlands into (1) freshwater wetlands of exceptional resource value, (2) wetlands of ordinary resource value, and (3) wetlands of intermediate resource value.

New York has adopted rules that categorize wetlands into four categories based on ecological associations, hydrologic features, pollution control features, cover types, and distribution and location (6 NYCRR Part 664.5).

West Eugene, Oregon developed a method for a plan based on "needs for protection" (City of Eugene 2000).

North Carolina created a GIS-based system that characterizes the "significance" of wetlands based on several landscape and function-based criteria (Gainey and Roise 1998).

5.4.1 Other Characteristics Used for Rating

Some freshwater wetlands in Washington are categorized in the Washington State Wetland Rating System based on important characteristics that are not specifically related to functions. These characteristics include rarity on the landscape, sensitivity to disturbance, and difficulty in restoring or creating such wetlands through mitigation efforts (Ecology 1991, Hruby 2003). At present these wetland types have been redefined for eastern Washington (Hruby 2003) and include:

- Bogs
- Alkali wetlands
- Mature and old-growth forested wetlands
- Vernal pools
- Wetlands identified by the Washington State Department of Natural Resources as "Natural Heritage wetlands"

Each of these types is described in more detail below. The list will be expanded as the wetland rating system for western Washington is revised. Currently, the 1993 edition of the rating system for western Washington identifies the following freshwater wetlands as ones with special characteristics: bogs, mature forested wetlands, and Natural Heritage wetlands.

5.4.1.1 Bogs

Many of the scientific studies of bogs have been published in Europe and the northern parts of the United States such as Minnesota and Maine. There has not been extensive research on bogs in Washington State. This summary of the literature is not intended to be a thorough synthesis but provides basic background information regarding characteristics of bogs requiring special consideration for management.

Predominance of Organic Soils

Bogs are peatlands (wetlands with organic soils) that have been classified according to their shape, chemistry, plant species, and vegetation structure (Gore 1983). The common factor in bogs is the presence of organic soils or peat, which result from the accumulation of poorly decomposed plant material. The optimum conditions for peat formation occur in cool, humid climates in a location with poorly drained soil.

The rate of peat accumulation is generally quite low, although it can vary with site-specific factors. Heathewaite and Gottlich (1993) report rates of accumulation ranging from 2 to 4 inches (5 to 10 cm) every 100 years. Durno (1961) lists a range of 0.5 to 4.3 inches (1.2 to 11 cm) accumulation every 100 years. In Washington, Rigg (1958) reports peat accumulation of 1 inch (2.5 cm) in 40 years for the west side of the Cascades and 1 inch in 50 years on the east side. Peat can be as little as 8 inches (20 cm) deep to over 45 feet (15 m) deep (Heathewaite and Gottlich 1993).

The three ways that peat is formed, described below, illustrate the lengthy process of peat and bog formation and help explain why bogs are almost impossible to recreate through compensatory mitigation (see below and in Chapter 6).

- In a “filled-lake” sequence, open water progresses to a sedge or moss community that gradually builds a mat over the water, evolving into a bog, bog forest, and then climax community (Conway 1949).
- “Paludification” occurs when bogs invade the surrounding forest. Sphagnum species cause a rise in the water table as peat layers compress and impede drainage (Heathewaite and Gottlich 1993).
- A “flow-through succession” occurs when surface flows are modified. Organic matter builds up to the point where surface flows are diverted around the peat mound. As it builds, the mound becomes isolated from groundwater, relying solely on precipitation as its water source (Klinger 1996).

Studies have shown, on the other hand, that many bogs remain very stable for thousands of years as a sphagnum moss/shrub community, even though succession to a forested community can occur (Klinger 1996).

Acidity and Poor Nutrients

Bogs have unusual hydrodynamics and chemistry for wetlands. They typically only receive precipitation and very localized surface runoff as their sources of water. As a result, many essential nutrients such as nitrogen occur in low concentrations. The upper layers of peat, formed by slowly decomposing sphagnum, are often strongly acidic, usually with a pH of 4 or less.

Bogs typically support plant species that are specially adapted to these harsh growing conditions. Sphagnum moss, as well as other mosses, usually dominate the system. Ericaceous shrubs such as Labrador tea (*Ledum gladulosum*) are also common.

Trees can grow in bogs but at a very slow rate due to the poor growing conditions. In studies in the Pacific Northwest, Rigg (1918) found tree growth in sphagnum peat soils was slow. Rigg determined that hemlock (*Tsuga heterophylla*) grew in sphagnum soils at a rate that was only 27% of its growth rate in productive upland soils, and that Douglas-fir (*Pseudotsuga menziesii*) grew in sphagnum at only 16% of its growth rate in upland soils. He measured the annual growth of western red cedar (*Thuja plicata*) as only 0.02 inches (0.6 mm).

Although persistent wet conditions, low soil oxygen, and high acidity are important factors, it is actually the lack of available nutrients, or the inability of plants to absorb nutrients because of acidity (Moore and Bellamy 1974), that most influences the flora of bogs. Most bog species have developed special adaptations to these conditions and out-compete more common wetland plants (Mitsch and Gosselink 2000). Therefore, this makes bog species susceptible to nutrient loading and changes in acidity (as well as alterations in water source that can precipitate these changes) that would enable other species to establish and dominate.

Bogs in Western and Eastern Washington

In western Washington, Kunze (1994) has characterized numerous types of peatlands, including bogs and fens. She identified 10 types of sphagnum bog communities in the Puget Trough region and 14 in the Olympic Peninsula/southwest Washington. They occur in the lowlands of the Puget Trough in depressions, oxbows, and old lake beds. These typically have a raised center with a moat around the edge. Bogs and fens also occur on the Olympic Peninsula and in southwest Washington where they can occupy basins, slopes, and flat to rolling ground, as well as forming along low-gradient streams. Bogs in the foothills of the Cascades include sloping bogs, which are transitional between sphagnum bogs and fens.

Peatlands in eastern Washington have not been classified to the extent of those in western Washington. However, 50 peatlands were identified by Rigg (1958). Forty-four of those identified were located in the northeastern corner of the state. They included fens associated with flowing water, bogs formed in depressions, and some along lake margins. Six peat systems were found in scabland channels and depressions on the Columbia Plateau.

Difficulty in Restoring Bogs

Researchers in Northern Europe and Canada have found that restoring bogs is difficult, specifically in regard to plant communities (Bolscher 1995, Grosvermier et al. 1995, Schouwenaars 1995, Schrautzer et al. 1996), water regime (Grootjans and van Diggelen 1995, Schouwenaars 1995), and/or water chemistry (Wind-Mulder and Vitt 2000). In fact, restoration may be impossible because of changes to the biotic and abiotic properties (Shouwenaars 1995, Schrautzer et al. 1996).

It is apparent that true restoration of a raised bog ecosystem is a long-term process. In *Restoration of Temperate Wetlands*, Joosten (1995) (in Roos) states:

> *Long term studies in bog regeneration indicate that restoration of bogs as self-regulating landscapes after severe anthropogenic damage is impossible within human time perspective, because the necessary massive re-establishment of bog key species and renewed accumulation of peat require centuries.*

Refer to Chapter 6 for more information on the challenges in restoring bogs.

5.4.1.2 Alkali Wetlands

Alkali wetlands are characterized by the occurrence of non-tidal, shallow saline water. In eastern Washington these wetlands contain surface water with specific conductance (a measure of salinity) that exceeds 3,000 micromhos per centimeter. These wetlands provide the primary habitat for several species of migratory shorebirds and are also heavily used by migrating waterfowl. They also have unique plants and animals that are not found anywhere else in eastern Washington. For example, the small alkali bee that is used to pollinate alfalfa and onion for seed production lives in alkali systems. This bee is a valuable natural resource for agriculture in the western United States and especially in eastern Washington (Deplane and Mayer 2000). The “regular” bees which pollinate fruits and vegetables are generally too large to pollinate the small flowers of these commercially important plants.

The salt concentrations in alkali wetlands have resulted from a relatively long-term process of groundwater surfacing and evaporating. These conditions cannot be easily reproduced through compensatory mitigation because the balance of salts, evaporation, and water inflows is hard to reproduce, and no references were found suggesting this has ever been attempted. Alkali wetlands are also rare in the landscape of eastern Washington. Of several hundred wetlands that were surveyed and visited by wetland scientists during field work for the state’s function assessment methods and the rating system for eastern Washington (Hruby et al. 2000, Hruby 2003), only nine could be classified as alkali.

5.4.1.3 Mature and Old-Growth Forested Wetlands

No mature or old-growth forested wetlands have ever been successfully created or restored through compensatory mitigation. A mature forested wetland may require 80 years or more to develop, and the full range of functions performed by these wetlands may take even longer (Stanturf et al. 2001). The actual time required to reconstruct old-growth forests and their soil properties (in contrast to mature forests) is unknown (Zedler and Callaway 2000). These forested wetlands provide important functions associated with wetlands as well as habitat functions associated with mature and old-growth forests. (Washington State Department of Fish and Wildlife 1999).

5.4.1.4 Vernal Pools

Vernal pool wetlands occur in eastern Washington and are formed when small depressions in bedrock or in shallow soils fill with snowmelt or spring rains. They retain water until the late spring when reduced precipitation and increased evapotranspiration lead to a complete drying out. The wetlands hold water long enough throughout the year to allow some strictly aquatic organisms to flourish, but not long enough for the development of a typical wetland environment (Zedler 1987). Vernal pools often contain upland species during the summer after they dry out and may be difficult to identify as jurisdictional wetlands during part of the year.

Vernal pools in the scablands are the first to melt in the early spring. This open water provides areas where migrating waterfowl can find food while other, larger bodies of water are still frozen. Furthermore, the open water provides areas for pair bonding of waterfowl (Friesz, personal communications). Thus, vernal pools in a landscape with other wetlands provide a critical habitat function for waterfowl (Hruby 2003).

5.4.1.5 Natural Heritage Wetlands

Natural Heritage wetlands are those that have been identified by scientists of the Washington State Natural Heritage Program as high-quality, relatively undisturbed wetlands, or wetlands that support state threatened or endangered plant species.

The Natural Heritage Program has identified important natural plant communities and species that are very sensitive to disturbance or threatened by human activities and maintains a database of these sites. The program’s web site states:

> *Some natural systems and species will survive in Washington only if we give them special attention. By focusing on species at risk and maintaining the diversity of natural ecosystems and native species, we can help assure our state's continued environmental and economic health.* (Washington Department of Natural Resources no date.)

5.4.2 Summary of Key Points

- Wetland rating systems provide a rapid method to identify, characterize, categorize, or estimate relative wetland functions and values. This information is used in regulating and managing wetlands.
- The rapid method most commonly used for analyzing wetlands in eastern and western Washington has been the *Washington State Wetland Rating System*. The rating system was designed to differentiate between wetlands based on a broad grouping of functions that they provide (hydrologic, water quality, and habitat) as well as other characteristics (listed in the next bullet). However, this rating system does not replace a full assessment of wetland functions that may be necessary to determine the level of performance for specific functions or plan and monitor a compensatory mitigation project.
- In the rating system, some wetlands are categorized because of their rarity on the landscape, sensitivity to disturbance, or difficulty in restoring or creating such wetlands through mitigation efforts, not because of the functions these wetlands perform. The wetland types in Washington that are included in the rating system because they have these other characteristics include bogs, alkali wetlands, mature and old-growth forested wetlands, vernal pools, and Natural Heritage wetlands.

5.5 Buffers

Buffers are another common element of wetland regulations. Buffers are vegetated areas adjacent to an aquatic resource that can, through various physical, chemical, and/or biological processes, reduce impacts from adjacent land uses. Buffers also provide the terrestrial habitats necessary for wildlife that use wetlands to meet their life-history needs. In this document we collectively call these processes that buffers provide the "functions" of buffers. Buffers and other adjacent upland areas provide habitat for other wildlife species that do not commonly use wetlands. This document does not address those functions of upland habitats.

The primary purpose of buffers is to protect and maintain the wide variety of functions and values provided by wetlands (or other aquatic areas). The physical characteristics of buffers—slope, soils, vegetation, and width—determine how well buffers reduce the adverse impacts of human development and provide the habitat needed by wildlife species that use wetlands. These characteristics are discussed in detail in this section.

The subject of buffers is well documented in the scientific literature. The research on buffers has occurred worldwide, and this section includes literature from a variety of regions when it was found to be relevant. In particular a variety of literature related to agricultural practices and vegetated filter strips from the north-central United States and south-central Canada is relevant to some agricultural practices in Washington State, especially east of the Cascades. In addition, studies on buffers in urban and suburban settings conducted in the Pacific Northwest region are clearly relevant.

The majority of research on buffers tends to focus on the processes that buffers provide to filter sediment or take up nutrients (i.e., their influence on water quality). Far fewer studies look at the influence of a buffer's physical characteristics on attenuating surface water flow rates, except as it relates to water quality. The long-term effectiveness of buffers in providing such mechanical and biological processes is not well documented in the literature and may represent a critical need for future research.

The literature on buffers related to wildlife is, in general, less focused. Most studies document the needs of a particular species or guild relative to distances for breeding or other life-history needs within a radius from aquatic habitats. There is substantial literature on the implications of habitat fragmentation and connectivity, some of it related specifically to agricultural practices, forestry practices, or the impacts of urbanization. This literature does not specifically address the role of buffers in providing connectivity between wetlands and other parts of the landscape. The reader is referred to Section 4.11 in Chapter 4, which discussed the effects of habitat loss and fragmentation.

Older research studied the tolerance limits of wetland wildlife for disturbance—how closely a disturbance can approach animals before they are flushed from wetlands—with particular emphasis on waterfowl. These studies tend to be older than 1990 and focus on the prairie pothole region of North America. Where the findings are germane and where they have not been superceded by more recent work, they are included.

In addition to papers on specific research studies, multiple compilations and syntheses of "buffer" literature have been completed since 1990. Synthesis papers were compiled by Castelle and other authors (1992, 1994, 2000) and another was compiled by McMillan (2000) as a master's thesis. These compilations include literature that was published prior to 1990, but much of the work they rely on is considered seminal to the effectiveness of buffers in protecting wetlands and contributing to habitat. Therefore these synthesis documents are used in this report as direct sources when no more recent research was found to supercede the earlier findings.

This section also cites literature related to stream buffers and riparian areas when the findings are relevant to the influence these areas have on the adjacent aquatic resource. The literature on stream buffers related to microclimate, water quality influences, and some habitat characteristics is particularly relevant because the ways buffers protect and maintain these functions is similar whether they are adjacent to streams or wetlands.

5.5.1 Terms Used to Describe Buffers

The scientific literature varies widely on the terms used to denote the area that serves to reduce impacts to wetlands from adjacent land uses and provide habitat for parts of the life-cycle of many species. Common terms include:

- Buffer
- Wetland setback

- Vegetated filter strip
- Buffer strip
- Riparian area
- Riparian zone
- Riparian corridor

These terms can be differentiated as those that are a product of regulations or policy language, and those that define or describe an ecological condition or location (Castelle et al. 1994). Terms such as "buffer," "wetland setback," or "vegetated filter strip" are most commonly applied in an administrative context to denote the landscape immediately adjacent to an aquatic resource, the dimensions of which are legally determined. The terms "buffer strip" or "vegetated filter strip" may imply a relatively undisturbed, vegetated area that helps attenuate the adverse effects of land uses adjacent to a wetland. For example, Norman (1996) provides this definition:

> *Buffer strips are strips of vegetated land composed in many cases of natural ecotonal and upland plant communities which separate development from environmentally sensitive areas and lessen these adverse impacts of human disturbance.*

The terms "riparian areas" or "riparian zones" are defined by many to denote ecologically discernable ecotones (transition zones) along aquatic resources where the presence or action of surface waters, or the presence and duration of shallow groundwater, influences the structure and composition of the vegetation community (Lowrance et al. 1995, Harper and MacDonald 2001). The term "riparian corridor" is defined by Naiman et al. (1993) as "encompass(ing) the stream channel and that portion of the terrestrial landscape from the high water mark towards the uplands where vegetation may be influenced by elevated water tables or flooding, and by the ability of the soils to hold water."

5.5.2 Functions Provided by Buffers

The literature is broadly consistent on the ways in which buffers can provide for the protection and maintenance of wetland functions. These include:

- Removing sediment
- Removing excess nutrients (phosphorous and nitrogen)
- Removing toxics (bacteria, metals, pesticides)
- Influencing the microclimate
- Maintaining adjacent habitat critical for the life needs of many species that use wetlands

- Screening adjacent disturbances (noise, light, etc.)
- Maintaining habitat connectivity

As noted by Castelle and Johnson (2000), buffers can be both ecological sources and sinks. They can control or limit the effects of land uses upslope of the aquatic resource (act as a sink), and they can contribute biological benefits to the aquatic resource (act as a source). Naimen et al. (1992) summarize the range of functions provided by buffers along streams as follows:

> *It is well known that riparian vegetation regulates light and temperature regimes, provides nourishment to aquatic as well as terrestrial biota, acts as a source of large woody debris,…regulates the flow of water and nutrients from uplands to the stream, and maintains biodiversity by providing an unusually diverse array of habitat and ecological services.*

These same functions can be attributed to wetland buffers (Castelle et al. 1992, Desbonnet et al. 1994, McMillan 2000).

The literature also describes the physical, chemical, and/or biological characteristics of a buffer that determine the functions it provides. The most frequently cited physical characteristics that influence the effectiveness of a buffer are:

- Landscape position of the buffer
- Vegetation characteristics (composition, density, and roughness—for example, downed material)
- Percent slope
- Soils
- Buffer width and length (adjacent to the source of impacts)

Only two of the physical characteristics noted above can be easily managed (vegetation characteristics and buffer width/length), while the others are characteristics that do not lend themselves to manipulation.

By far the issue of greatest interest with respect to buffers is the question of how wide a buffer needs to be in order to be effective in protecting a wetland (or other aquatic resource). While the literature is unanimous that buffers provide important functions that protect wetlands and provide essential habitat for many species, there is wide-ranging discussion about how much buffer is necessary to be effective in providing a particular level of function (Young 1980, Booth 1991, Castelle et al. 1994, Norman 1996, Dosskey 2000, McMillan 2000, Rickerl 2000).

For ease of discussion as to the effective widths of buffers, the functions of buffers listed above are grouped into two major categories:

- Water quality (discussed in Section 5.5.3)
- Wildlife habitat (discussed in Section 5.5.4)

Buffers and their influence on wetland hydroperiod, as described in the few studies found on this subject, are summarized in the shaded box on the next page.

The following literature sources are generally consistent in describing what functions buffers provide to aquatic resources as well as the physical parameters that influence a buffer's ability to provide these functions: Budd et al. (1987), Phillips (1989), Castelle et al. (1992, 1994), Naiman et al. (1992), Belt and O'Laughlin (1994), Desbonnet et al. (1994), Norman (1996), Dillaha and Inamdar (1997), Dosskey (2000), Van der Kamp and Hayashi (1998), Liquori (2000), McMillan (2000), Todd (2000), Townsend and Robinson (2001), Dosskey (2001).

Buffers alone have limited influence on wetland hydroperiod

As described in detail in Chapter 3, human land uses such as agricultural practices, clearing, and land development alter the movement and storage of surface water and groundwater within a wetland's contributing basin. These changes can significantly affect the hydroperiod of wetlands and other aquatic resources, causing an adverse effect on many wetland functions (Azous and Horner 2001). There is little published literature on the effectiveness of buffers in ameliorating the effect of changes in land use within the contributing basin on wetland hydroperiod. Some of the literature determined that wetland buffers are far less effective at maintaining wetland hydroperiod than other mechanisms such as controlling impervious surfaces and utilizing effective stormwater management practices (Herson-Jones et al. 1995).

Research in the Puget Sound Basin has agreed that changes in the land cover type in the contributing basin have a stronger influence on the resulting hydroperiod of the wetland than the buffer does (Booth 1991, Azous and Horner 2001). An exception may be for wetlands that have a very small contributing basin. However, the rate and manner in which stormwater enters the wetland following land use changes in the contributing basin will most often shift from sheet flow and interflow to one or more point sources, resulting in a potential change in hydroperiod. Based on hydroperiod models using the HSPF model (Hydrologic Simulation Program Fortran, U.S. EPA) for areas west of the Cascades, the wetland will tend to receive more water more quickly in the fall and will receive less water for a shorter period in the spring, resulting in a shift in the seasonal hydroperiod.

Buffer width is usually not sufficient to counteract the influence of land use changes and stormwater management facilities within the wetland's contributing basin.

5.5.3 Buffers and Protection of Water Quality

Buffers protect the water quality of wetlands through four basic mechanisms:

- They remove sediment (and attached pollutants) from surface water flowing across the buffer
- They biologically "treat" surface and shallow groundwater through plant uptake or by biological conversion of nutrients and bacteria into less harmful forms
- They bind dissolved pollutants by adsorption onto clay and humus particles in the soil
- They help maintain the water temperatures in the wetland through shading and blocking wind

Literature describing the different ways that buffers maintain and improve water quality in wetlands and other aquatic areas is abundant. There is also considerable research on the effective widths that provide a relative percentage of removal of sediments, nutrients, and some toxics emanating from various sources. Four categories of water quality improvement are discussed below:

- Removing sediment
- Removing nutrients
- Removing toxics and pathogens
- Maintaining microclimate

For each of these categories, a summary is provided on what the literature says about the relationship between buffer width or other characteristics and the buffer's effectiveness in providing that type of water quality improvement. A summary table is included that lists the range of buffer widths for each category and the literature references that substantiate those findings.

5.5.3.1 Removing Sediment

Characteristics that Influence a Buffer's Ability to Remove Sediment

A buffer's ability to remove sediment from surface water flows depends upon several physical characteristics of the buffer. Sediment removal occurs when (Castelle et al. 1992, Dillaha and Inamdar 1997, Phillips 1989):

- Flows are slowed sufficiently to allow particles to fall out
- Physical filtering by vegetation and roots mechanically removes sediments from the water column
- The slope of the buffer is of a low enough gradient to preclude formation of rills and scouring
- There is large woody debris on the ground to create roughness
- The infiltration rate of the soils allows water to move through the soils rather than on the surface

The way sediment-laden water enters a buffer influences the ability of the buffer to slow the flows sufficiently to allow sediment deposition. Several studies noted that vegetated buffers are only effective at removing sediments if sediment-laden waters enter the buffer as sheet flow, rather than in channels or rivulets (Phillips 1989, Booth 1991, Castelle et al. 1992, Desbonnet 1994, Belt and O'Laughlin 1994, Sheridan et al. 1999). Norman (1996) cites work conducted by Schueler in 1987 that found buffers in urban settings were most effective at removing sediments where slopes were less than 5% and waters entered the buffer in shallow, dispersed sheet flow. Norman surmised that, "The rate of removal of pollutants appears to be a function of the width, slope, and soil permeability of the (buffer) strip, the size of the contributing runoff area, and the runoff velocity."

In other research, Sheridan et al. (1999) found that the greatest reduction in sediment loading occurs in the initial "treatment" stages using a vegetated filter strip that is managed and mowed. Their research found the greatest removal of sediments (56 to 72%) and reduction in flow rates occurs in the outer portion of a vegetated filter strip (the strip closest to the source of sediment). Grass filter strips provided removal ranging from 78 to 83% of suspended sediments.

The ability of a buffer to provide physical filtering of sediments also depends on the condition of the vegetation and the surface roughness. Belt and O'Laughlin (1994) noted that when vegetation, rocks, or other obstructions were eliminated from the buffer surface, sediment-laden waters flowed further into (or through) a buffer. Buffers were found to be effective in removing sediments only if flows were shallow and broad, not narrow and incised. The presence of woody debris and vegetative obstructions on the ground surface (roughness) was found to slow flows, inhibit the formation of rills, and facilitate sediment deposition.

In contrast, hydrologic models created by Phillips (1989) estimated that surface roughness would be of minor concern and buffer width was not critical as long as a minimum 49-foot (15 m) buffer was maintained. This study was based on estimated models, whereas Belt and O'Laughlin's work was based on field measurements.

Phillips (1989) also emphasized the importance of slope. He states, "Results show that where solid-phase pollutants transported as suspended or bed-load in overland flow are the major concern, slope gradient is the most critical factor, followed by soil hydraulic conductivity." Slope gradient is critical because on slopes greater than 5% sheet flow can start to become channelized. Channelized flows have faster rates, more erosive powers, and less contact with vegetation (Norman 1996). Faster moving water has the capacity to carry fine sediment particles farther than slower flows, even moving through dense vegetation.

In his research in urbanizing settings, Booth (1991) notes that buffers adjacent to aquatic resources may have limited ability to filter and slow flows caused by stormwater. He found (1) in some instances the buffers no longer existed in a natural vegetated condition, or (2) once development occurred and the buffer was subdivided into multiple private ownerships, maintaining an intact buffer was not possible, or (3) the increased volumes and rates of flows were too significant to be controlled by conditions within a vegetated buffer.

Buffers were found to facilitate reduction of sediment from active agricultural fields in several studies:

- Welsch (1991) found that a three-tiered buffer system on a shallow slope, with the first tier (closest to the source of sediment) composed of dense herbaceous vegetation, maximized sediment removal. (See Section 5.5.6 for a discussion of the three-tiered system.)

- Dosskey (2001) noted in agricultural settings that vegetated buffers retain pollutants by reducing the flow rates and filtering surface runoff from fields.

- Assessing management options to control non-point-source pollution (sediment, nitrogen, and phosphorus) in agricultural settings, Yocom et al. (1989) recommended the use of vegetated filter strips between actively cropped land and adjacent wetlands.

Buffer Width and Effectiveness in Removing Sediment

As noted above, the ability of a buffer to remove sediment is based on the condition of the buffer and its slope as well as the characteristics of the incoming sediment. The following variables all contribute to the sediment removal effectiveness of a buffer:

- The velocity of sediment transport (in surface water)

- The size of sediment particles from the source materials

- The density of the vegetation present

- The presence and extent of large woody debris

- Surface roughness within the buffer

However, the relationship between the width of the buffer and its effectiveness is non-linear. The largest particles and the greatest percentage of particles are dropped in the outer portions of the buffer (closest to the source of sediment). In these outer areas, the rate of surface flow begins to diminish as the water is slowed by vegetation and woody debris. Slower water movement allows particles to drop out of the water column.

In 1982, Wong and McCuen derived a formula to model a buffer's ability to remove sediments based on sediment particle size, the slope within the buffer, the rate of surface runoff, and the amount of vegetation and woody debris (roughness) in the buffer (Castelle et al. 1994). The model predicted that there would be a point of relative diminishing returns for function vs. width. For example, "If the sediment removal design criteria were increased from 90 to 95% on a 2% slope, then the buffer widths would have to be doubled from 30.5 to 61 m (100 to 200 ft)." In other words, the model predicted that the width of the buffer would have to double to achieve an additional 5% removal of sediment after 90% of it had already been removed from the water column. Desbonnet et al. (1994) determined that a small buffer (7 feet [2 m]) could effectively remove up to 60% of suspended sediment, while a buffer of up to 82 feet (25 m) would be needed to remove 80%.

These findings are consistent with others who have found that progressively larger buffer dimensions are required to filter out finer particles (Norman 1996). These and other studies are summarized in Table 5-1.

See Section 5.5.5 for discussion of the ability of buffers to continue providing sediment removal over the long term.

Table 5-1. Summary of studies on sediment control provided by buffers of various widths.

Author(s)	Date	Buffer Width	Comments
Broderson	1973	200 feet (61 m)	Effective sediment control "even on steep slopes" as cited by Castelle and Johnson (2000)
Desbonnet et al.	1994	6.6 – 82 feet (2 – 25 m)	60% removal in 6.6 feet (2 m); 80% removal required 80 feet (25 m)
Desbonnet et al.	1994	16 – 49 feet (5 – 15 m)	On grassy buffers on slopes with less than 5% slope, removed all but the finest particles. Cited by McMillan (2000)
Ghaffarzadeh et al.	1992	16 – 49 feet (5 – 15 m)	Found 85% removal in 30-foot (9.1 m) buffers as cited by Castelle and Johnson (2000)
Horner and Mar	1982	200 feet (61 m)	80% of sediments. As cited by Castelle and Johnson (2000)
Lynch, Corbett, and Mussallem	1985	98 feet (30 m)	75 to 80% removal of sediment from logging activities into wetlands. As cited by Castelle and Johnson (2000)
Norman	1996	9.8 feet (3 m): sands 49.9 feet (15.2 m): silts 400 feet (122 m): clays	Distances required for effective removal of progressively smaller particle sizes
Wong and McCuen	1982	100 – 200 feet (30.5 – 61 m)	90% at 100 feet (30 m), need 200 feet (61 m) to obtain 95% removal effectiveness. Cited by Castelle et al. (1994)
Young	1980	80 feet (24.4 m)	92% sediment removal rate from feedlot through vegetated buffer strip. Cited by Castelle et al. 1994

5.5.3.2 Removing Nutrients

Characteristics that Influence a Buffer's Ability to Remove Nutrients

Nutrients are transported into wetlands via sediment-laden water or dissolved in surface or shallow subsurface flows. The primary nutrients of concern are nitrogen and phosphorous. Buffers remove nitrogen and phosphorous through a variety of mechanisms that are similar to the mechanisms present within the wetland itself, as described in Chapter 2.

As much as 85% of phosphorous in surface waters is bound to sediments (Karr and Schlosser 1977) and thus can be removed via sediment removal in buffers. Phosphorus and other nutrients may be effectively reduced in surface waters by filtering and uptake; however, dissolved forms of nitrogen are not affected by surface processes and can be more effectively removed in the buffer through subsurface contact with fine roots

(Muscutt et al. 1993, Townsend and Robinson 2001). Lowrance et al. (1995) confirm that the areas where improvements in water quality are the most effective are where precipitation moves across, through, or near the rooting zone of a forested buffer. These findings are similar to those of Phillips (1989), who found that longer contact of dissolved pollutants through wider vegetated buffers was the most important factor for effective removal.

Buffer Width and Effectiveness in Removing Nutrients

It is difficult to compare studies of buffer width and effectiveness at removing nutrients because the basic parameters of the studies differ greatly. Some studies were conducted in field settings while others occurred in experimentally designed plots. There were differences in the loading rate of nutrients, the types of soils, and the vegetation in the buffers. Some studies examined only nitrogen or phosphorous removal, whereas others combined different nutrients. The result is that reported effectiveness of buffer widths for removing nutrients ranges from a few meters to hundreds of meters. Studies are listed in Table 5-2.

In a synthesis of research on nitrogen removal, McMillan (2000) found nitrogen can be effectively removed in buffer strips ranging from 20 to 98 feet (6 to 30 m) wide. He cites work by two research groups (Patty et al. 1997, Daniels and Gilliam 1996) that 47 to 99% removal of nitrogen can be achieved in buffers ranging from 20 to 66 feet (6 to 20 m) wide. This is not totally consistent with synthesis results presented by Desbonnet et al. (1994) that "well configured" buffers (with ideal slope, soils, and vegetation) as small as 30 feet (9 m) could reduce as much as 60% of nitrogen, while 197-foot (60 m) buffers would be necessary for 80% nitrogen removal.

The literature also describes a range of buffer widths necessary for phosphorus removal. Studies of buffers as small as 13 feet (4 m) wide and as large as 279 feet (85 m) wide found phosphorus removal rates of 50% to over 90% (see Table 5-2).

Overall, a consistent pattern emerges from the literature. The largest relative percent removal of phosphorus occurs within the outer portions of the buffer (closest to the source), while larger buffers are required to remove increasingly more of the nutrients. This consistent finding substantiates the conclusions of many that initial contact causes sediment-associated nutrients to be deposited, while dissolved nutrients require longer residence time and prolonged contact with vegetation for effective uptake (removal from the water column) to occur.

Castelle and Johnson (2000) surmised in their literature review that nutrient removal may have a similar non-linear relationship to buffer width as sediment removal. However, Phillips (1989) found that buffer width was a more critical element for dissolved nutrients (especially nitrogen), because wider buffers provided more prolonged contact with the rooting zone and time for uptake and conversion. Phillips did not report widths of buffers related to a certain percent of removal or effectiveness.

Limited research has been done on the long-term effectiveness of buffers for nutrient removal when there is an ongoing nutrient source present on the outside edge of the buffer. See Section 5.5.5 for a discussion.

Table 5-2. Summary of studies on nutrient removal provided by buffers of various widths.

Author(s)	Date	Width	Comments
Daniels and Gilliam	1996	20 – 66 feet (6 – 20 m)	47-99% removal of nitrogen, cited by McMillan (2000)
Desbonnet et al.	1994	30 feet (9 m): 60% removal 197 feet (60 m): 80% removal	Small buffers could have effective removal rates for nitrogen; much larger buffers are necessary for a significant increase in effectiveness
Desbonnet et al.	1994	Averages: 39 feet (12 m): 60% 279 feet (85 m): 80%	When all the findings from the literature synthesis were averaged, the average removal efficiencies were non-linear: larger buffers were needed for increases in effectiveness
Dillaha	1993	15 feet (4.6 m): 70% 30 feet (9.1 m): 84 %	Percent removal of suspended solids and their associated nutrients with vegetated filter strips. As cited in Todd (2000)
Dillaha	1993	15 feet (4.6 m): 61 % 30 feet (9.1 m): 79 %	Removal of phosphorus with vegetated filter strips. As cited by Todd (2000)
Dillaha	1993	15 feet (4.6 m): 54% 30 feet (9.1 m): 73%	Removal of nitrogen with vegetated filter strips. As cited by Todd (20000)
Doyle, Stanton and Wolf	1977	12.5 feet (3.8 m) forested 13.1 feet (4 m) grass	Reduced nitrogen, phosphorus, and potassium levels. Cited by Castelle and Johnson (2000), McMillan (2000)
Edwards et al.	1983	98 feet (30 m)	50% removal rate of phosphorus. As cited by McMillan (2000)
Lowrance et al.	1992	23 feet (7 m)	Forested buffer zones were effective at removing nitrate through plant uptake and microbial denitrification
Lynch, Corbett and Mussallem	1985	98 feet (30 m)	Forested buffers reduced soluble nutrient levels from logging activities to “appropriate” levels. Cited by Castelle and Johnson (2000)
Patty et al.	1997	20 – 66 feet (6 – 20 m)	47 - 99% removal of nitrogen, as cited by McMillan (2000)
Peterjohn and Correll	1984	164 feet (50 m)	Forested buffer strips provided “dramatic reductions in nutrient loads from crops” as cited by Belt and O’Laughlin (1994)

Author(s)	Date	Width	Comments
Shisler, Jordan, and Wargo	1987	62 feet (19 m)	Forested riparian buffers effectively removed up to 80% and 89% of phosphorus and nitrogen, respectively. Cited by Castelle and Johnson (2000)
Thomson et al.	1978	39 – 118 feet (12 – 36 m)	Found a range of removal effectiveness of 44 to 70%. As cited by McMillan (2000)
Vanderholm and Dickey	1978	> 853 feet (260 m)	Removal of 80% of nutrients, solids, and BOD from feedlot runoff with shallow (<0.5%) buffer slopes. Cited in Castelle et al. (1998)
Young et al.	1980	69 feet (21 m): 67% removal 89 feet (27 m): 88% removal	Removal of phosphorus, as cited by McMillan (2000)
Xu, Gillam, and Daniels	1992	33 feet (10 m)	Significant reductions in nitrate through a mixed herbaceous and forested buffer strip. As cited by Castelle and Johnson (2000)

5.5.3.3 Removing Toxics and Pathogens

Characteristics that Influence a Buffer's Ability to Remove Toxics and Pathogens

A buffer's ability to remove toxicants and pathogens is one of the least thoroughly studied. At this time, it represents a significant data gap. Castelle and Johnson (2000) note the lack of research on pathogens such as fecal coliform bacteria and toxicants such as pesticides. Many of the studies they examined are quite old, but little recent research was found to supplement these older studies. Therefore, the conclusions presented from the synthesis of the previous work are provided here.

Gilliam (1994) also confirms in his work that little to no research is available on the effective removal of fecal coliforms or various pesticides. Much of the work assessed the effectiveness of removal of nutrients and toxics, without identifying a dimension of width necessary to provide that removal.

Toxics (pesticides and metals) can be removed by buffers through sedimentation, biological uptake by vegetation, adsorption onto clay or humus particles in the soil of the buffer, or degradation of the toxics through biochemical processes (McMillan 2000, Patty et al. 1997).

As mentioned in the discussion of sediment removal, Welsch (1991) described the use of a three-tier buffering system for the most effective removal of sediments and their associated toxics. The outermost tier (closest to the source of impacts) was a densely vegetated filter strip, managed to ensure no erosion or rill formation. He found the most effective removal of sediments and the toxics adhered to sediment particles was through surface sheet flows through the vegetated filter strip. The middle tier was subject to some management activities (limited agriculture or limited tree harvest), while the innermost tier was undisturbed natural vegetation. Dissolved nutrients and some toxics were not affected by physical filtering unless there was prolonged contact with the rooting zone through the shallow groundwater table. See Section 5.5.6 for further discussion.

Castelle and Johnson (2000) note that the apparent effectiveness of small buffers in removing toxics is due to the adsorption of many toxics to sediment particles. When vegetated buffers are effective at filtering sediments, they will also be effective at filtering those toxics and nutrients adhered to the sediments.

One study in Saskatchewan (Donald et al. 1999) found that the concentrations of agricultural pesticides and herbicides in wetlands were influenced by the timing of precipitation relative to the applications of the chemicals. They noted that buffer width may influence exposure of the wetland to these chemicals, but they did not quantify what buffer widths related to the effectiveness of removing chemicals.

Buffer Width and Effectiveness in Removing Toxicants and Pathogens

Table 5-3 summarizes studies on the effectiveness of toxicant and pathogen removal provided by buffers of various widths.

Table 5-3. Summary of studies on pathogen control provided by buffers of various widths.

Author(s)	Date	Width	Comments
Doyle, Stanton and Wolf	1977	12.5-foot (3.8 m) forested buffers 13.1-foot (4 m) grass buffers	Reduction in fecal coliform bacteria levels as cited by Castelle and Johnson (2000)
Grismer	1981	98-foot (30 m) grass filter strip	Removal of 60% of fecal coliform bacteria as cited by McMillan (2000)
Young et al.	1980	115-foot (35 m) grass buffer	Reduced microorganisms to acceptable levels. Cited by McMillan (2000)

5.5.3.4 Maintaining Microclimate

The influence of buffers on microclimate is most often thought of in the context of shading for maintaining water temperature. This is well documented in the literature in relation to the effects on streams (Johnson and Stypula 1993, Belt and O'Laughlin 1994, Castelle and Johnson 2000, McMillan 2000). In those documents, literature focused on streams and their buffers is almost exclusively relied upon to discuss the influences of buffers on water temperature. No literature was found that specifically examined the influence of buffers on the water temperatures and microclimates within wetlands.

Although it may be tempting to deduce that the benefit of forested shade in moderating water temperatures is the same in wetlands as in streams, it is not reasonable to apply findings on the dimensions of stream buffers for shading directly to wetlands. There are too many variables related to differences in water budgets (e.g., the relative influence of groundwater on a seasonal basis, whether the wetland has an inlet/outlet, etc.). Also, the physical configurations of a large open-water wetland, a small fully vegetated wetland, and a linear stream corridor may not provide reasonable parallels. With these limitations in mind, some relevant findings are provided below.

Forests can create shade and also block the wind, which can help moderate temperatures in adjacent aquatic systems (McMillan 2000). Stable water temperature helps maintain water quality because cooler water can carry higher loads of dissolved oxygen, which is important for many aquatic biota. Warmer water can also result in a looser bond between sediment particles and nutrients, which could result in an increase in nutrient loading in warmer aquatic systems (Karr and Schlosser 1977).

Microclimate influences can also extend from large wetlands into the adjacent forests. Harper and MacDonald (2001) conducted research on boreal forests near lakes and found a “distinct lake edge community” of about 131 feet (40 m) width. The lake edge community tended to have greater structural diversity, less canopy cover, fewer snags, greater amounts of coarse woody debris, and greater number of saplings and mid-canopy trees than the interior forest. Changes in the distribution of vegetation species were along a shade tolerance gradient, but the authors postulated that moisture gradient or water table depth also had an influence. Their research was conducted within forests adjacent to open water lakes, but it would be valid to extrapolate their findings to forested communities adjacent to permanent, large open wetlands that would create the same “light and shade” effect. The findings imply that large open aquatic systems influence the adjoining upland community for over 120 feet (37 m) distance into the interior of the forested buffer. Thus buffers not only influence temperatures and wind effects in a wetland but research identifies that large aquatic systems may have a reverse positive influence on the vegetation structure and species diversity of the buffer. This can thereby affect some of the habitat discussed later in this chapter.

Table 5-4. Summary of studies on the influence of microclimate provided by buffers of various widths.

Author(s)	Date	Width	Comments
Harper and MacDonald	2001	Approx. 131 feet (40 m)	Influence of large aquatic systems on adjacent upland forest composition and structural complexity

5.5.3.5 Summary of Key Points

- The use of buffers to protect and maintain water quality in wetlands (removing sediments, nutrients, and toxicants) is best accomplished by ensuring sheet flow across a well vegetated buffer with a flat slope (less than 5%).
- Significant reductions in some pollutants, especially coarse sediments and the pollutants adhered to them, can be accomplished in a relatively narrow buffer of

16 to 66 feet (5 to 20 m), but removal of fine sediments requires substantially wider buffers of 66 to 328 feet (20 to 100 m).

- Removal of dissolved nutrients requires long retention times (dense vegetation and/or very low slope) and, more importantly, contact with fine roots in the upper soil profile (i.e., soils that are permeable and not compacted). Distances for dissolved nutrient removal are quite variable, ranging in the literature from approximately 16 to 131 feet (5 to 40 m).

- The literature is consistent in finding that it takes a proportionally larger buffer to remove significantly more pollutants because coarse sediments and the pollutants associated with them drop out in the initial (outer) portions of a buffer. It takes a longer time for settling, filtering, and contact with biologically active root zones to remove fine particles and dissolved nutrients.

- The role of buffers in protecting the microclimate of streams is well documented and may be applicable to wetlands, but no specific data on buffers and wetland microclimate maintenance were found.

5.5.4 Buffers and Wildlife Habitat

Wetland buffers are essential to maintaining viable wildlife habitat because they perform three overlapping functions:

- Buffers can provide an ecologically rich and diverse transition zone between aquatic and terrestrial habitats, including necessary terrestrial habitats for many wildlife species that use wetlands

- Buffers can screen wetland habitat from the disturbances of adjacent human development

- Buffers may provide connectivity between otherwise isolated habitat areas

In regard to wildlife, most of the scientific research is not directly focused on the effectiveness of buffers for maintaining individuals or populations of species that use wetlands. Some of the research simply documents use of upland habitats adjacent to wetlands by wildlife to meet their life-history needs. For example, a substantial body of research identifies the distances that amphibians may be found away from a wetland edge, but what is not well documented are the implications to amphibian populations by providing buffers that are smaller than those identified ranges.

The following discussion summarizes the literature on buffers related to wildlife that use wetlands for the three essential functions listed above. Several documents are cited that represent a synthesis of scientific literature on the effectiveness of buffers for protecting wildlife-related functions of wetlands. Even though these documents include some research conducted prior to 1990, they have been included where relevant.

There is substantial literature on the implications to wildlife populations from fragmenting habitats as a result of human activities. However, this research was not necessarily conducted to address the effectiveness of various buffer widths. The literature on this topic is mentioned because of the management implications for the long-term viability of wetland-dependent species. The reader is referred to Section 4.11 in Chapter 4 for a detailed discussion of habitat connectivity and fragmentation.

5.5.4.1 Maintaining Terrestrial Habitat Adjacent to Wetlands

Buffers provide a transition between aquatic and terrestrial environments and are a critical component of the habitat of wildlife that use wetlands. The specific habitat functions provided by wetland buffers include:

- Sites for wildlife for foraging, breeding, and nesting
- Cover for escape from predators or adverse weather
- Source of organic matter that provides habitat structure and food
- Areas for dispersal and migration related to both individuals and populations (buffers may connect or be part of corridors)

As defined previously, buffers are predominantly upland habitat communities that lie adjacent to aquatic habitats. They are a different habitat type than the wetland and their presence increases habitat heterogeneity by providing niches for more species. First described by Leopold (1933) as the "edge effect," this phenomenon features higher use of transition zones by wildlife, particularly between aquatic and terrestrial habitats. It has been demonstrated in studies of birds (Beecher 1942, McElveen 1977), mammals (Bider 1968), and amphibians (Bury 1988). The same pattern has been demonstrated in the Pacific Northwest in studies by Oakley et al. (1985), Knight (1988), and Cross (1988). Research conducted in the Puget Sound lowlands confirmed the relationship between habitat diversity and species richness when the greatest species richness of birds and small mammals was found within the first 1,640 feet (500 m) adjacent to a wetland boundary (Richter and Azous 2001b, 2001c).

Protection of upland areas adjacent to wetlands is critical to helping ensure that wetland-dependent wildlife populations have access to the habitat features necessary to meet their survival requirements. Wetland-dependent species, such as many amphibians, aquatic invertebrates, waterfowl, and some mammals, require access to wetlands for critical stages of their life-history. Many more species use wetlands, as well as other aquatic systems such as streams, lakes, or rivers, to meet various life-history needs. Research shows that species that were assumed to be dependent upon wetlands also depend upon adequate and appropriate upland habitats to maintain viable populations (Foster et al. 1984, Bury 1988, Washington Department of Wildlife in Castelle et al. 1992).

In addition, vegetated buffers protect habitat in wetlands by maintaining the microclimate (through temperature moderation), as discussed previously, and by providing a source of organic matter to aquatic systems. This includes both large organic debris (logs, root wads, limbs), which provides habitat structure in aquatic environments, and particulate and dissolved organic matter, which provides a source of food for invertebrates (Brown 1985, Groffman et al. 1991).

In coastal wetlands in South Carolina, Braccia and Batzer (2001) found that large woody debris within wetlands was critical for both aquatic and terrestrial invertebrate populations. They identified that the source of the large woody debris within the wetlands was from the adjacent uplands. The forest conditions in adjacent uplands therefore can have a significant influence on wetland biota because the aquatic invertebrates form the foundation of many food chains in aquatic settings (Castelle et al. 1994).

Buffer Width and Effectiveness in Protecting Wetland Habitat and Providing Habitat in Adjacent Uplands

This section summarizes the literature that identified ranges of widths of uplands that protect wetland habitat and/or that provide adjacent upland habitat for wildlife species that use wetlands. The literature presents findings in a variety of ways. Some studies identify the distance that target species range from a wetland source, while other researchers identified the distances that species travel between wetlands. Synthesis documents outlined recommendations for buffer widths based on a review of research findings. Some of the literature identified use of habitats by broad categories of wildlife guilds, while other studies focused on limited guilds or even individual species.

It is important to understand that the range of buffer widths identified and discussed in the literature is a reflection of many variables including the objectives of the research, the species/guilds studied and their varied life-history needs, and the methods of the research. Thus, it is not appropriate to choose a single study or buffer dimension to justify a buffer dimension, whether large or small. It is critical to incorporate the life-history requirements of the range of targeted species when considering buffer dimensions. Synthesis documents clarify that a range of upland habitat buffer dimensions may be appropriate depending upon site considerations, landscape context, and targeted species.

For example, in summarizing the literature he reviewed on buffer effectiveness, McMillan (2000) concluded, “An appropriate buffer to maintain wildlife habitat functions for all but the most highly degraded wetlands would be comprised of native tree and shrub vegetation and range from 30 to 100 meters [98 to 328 feet].” Other authors have reached similar conclusions, with their buffer recommendations varying depending on the type of wildlife, life-history stage, intensity of adjacent land use, and surrounding landscape (Groffman et al. 1991, Castelle et al. 1992, Desbonnet et al. 1994, Semlitsch 1998). Because there is often substantial information on the needs for some specific wildlife groups, the research findings that are relevant for birds, amphibians, reptiles, and mammals are provided below. Following this discussion, Table 5-5 provides a summary of literature on general habitat needs in relation to buffer sizes.

One element that was not found for this synthesis was the implications of the condition of the upland buffer relative to its provision of wildlife habitat. In several studies on the use of upland buffers by native species, the study identified that the buffer was upland forest. However, no studies were reviewed for this synthesis that compared wildlife use of mature forested buffers with buffers composed of meadow, shrubland, logged forest, or younger forests. Some research has identified the importance of intact forest habitat to wetland-related species (Azous and Horner 2001, Richter 1997), but a comparison study was not found for this synthesis.

Birds

The research on birds ranges from studies in individual species to summaries on bird species richness. A tremendous amount of research on waterfowl exists, with the majority being conducted in the prairie pothole region of the United States. This section focuses on studies or syntheses that are relevant to the Pacific Northwest.

The Puget Sound Stormwater Management Research Program found that a distance of 1,640 feet (500 m) from a wetland edge was necessary to account for total species richness of birds (Richter and Azous 2001b). In a study of bird use of freshwater wetlands in urban King County, Washington, Milligan (1985) determined that bird species diversity was strongly correlated with the percentage of the wetland boundary that was buffered by at least 49 feet (15 m) of trees and shrubs.

In eastern Washington, Foster et al. (1984) determined that 68% of waterfowl nests were in upland areas within 98 feet (30 m) of the wetland edge, whereas it would take a 312-foot (95 m) buffer to encompass 95% of the nesting sites.

Temple and Cary (1988) created a computer model whose results may relate to the breeding success of forest birds using wetland buffers. Estimating the effects of habitat fragmentation on birds breeding in the interior of forests in Wisconsin, their model predicted that nesting success was strongly correlated to distance to the edge of a forest. The computer model predicted a success rate of 70% for nests greater than 656 feet (200 m) from the forest edge, 58% for a distance of 328 to 656 feet (100 to 200 m), and only 18% for nests less than 328 feet (100 m) from the forest edge. Applying these findings to wetland buffers, those less than 100 feet (30 m) in width might not be expected to support bird species that nest in forest interiors. The authors concluded that without "recruits" (birds moving into appropriate habitat niches from farther afield), the continued fragmentation of forest habitats could lead to local extinction of populations of birds that use the interior of forests.

Amphibians

The research on amphibians and buffers in relation to their habitat needs comes both from studies in the Pacific Northwest and literature summaries from around the United States. Findings are rather consistent in that amphibians range substantial distances from breeding locations in a wetland to fulfill their life-history needs. On the west side of the Cascades there appears to be a preference for forested habitats adjacent to breeding sites, and urban uses near breeding sites seem to have a negative influence on amphibian abundance.

Detailed findings include:

- A study in the Puget Sound lowlands documented a decline in amphibian richness in wetlands where forest in the contributing watershed was diminishing; results were not linked to buffer dimensions (Richter and Azous 2001a).
- In a study in King County by Ostergaard (2000), the greatest use of stormwater ponds by native breeding amphibians was found when 3,280 feet (1,000 m) of forested habitat was available adjacent to the pond.
- A study of pond-breeding salamanders found that a buffer of 534 feet (164 m) would be needed to encompass 95% of adult and juvenile salamanders; this buffer range may apply to other similarly mobile species (Semlitsch 1998). Buffers of 98 to 328 feet (30 to 100 m) were recommended along riparian zones depending upon slope, stream width, and adjacent use (Semlitsch 1998).
- Salamanders use upland habitats over 1,969 feet (600 m) from the edge of wetlands for non-breeding life-history stages. Sustaining viable wetland-dependent amphibian species requires maintaining the connection between wetlands and terrestrial habitats. (Semlitsch 1998).

See Table 5-5 for further information on these studies.

In addition, Knutson et al. (1999) found a positive correlation between the presence of forest around the perimeter of the wetland and amphibian abundance, and a negative correlation to urban land uses on the perimeter.

Reptiles

Research on reptiles and buffers in the Pacific Northwest was not found. Research on freshwater turtles in North Carolina found that turtles used a wide area for nesting and terrestrial hibernation in uplands surrounding the ponds where breeding occurred (Burke and Gibbons 1995). They found that a 902-foot (275 m) buffer was required to protect 100% of the nest and hibernation sites. Protecting 90% of the sites required a 240-foot (73 m) buffer. The authors concluded that most buffer requirements are inadequate to protect turtle habitat for all stages of their life-history.

Mammals

Use of wetlands by mammals depends upon adjacent uplands. The literature indicates that even a wetland-dependent mammal such as a beaver uses upland habitats an average of 100 feet (30 m) from the wetland edge in eastern Washington and over 300 feet (100 m) distant in western Washington (Castelle et al. 1992). Research on small mammals found the greatest concentration of species near riparian corridors, with some species found within that riparian corridor that were not found farther away in upland habitats (Cross 1985).

Dimensions of effective buffers for mammals are more difficult to discern from the literature because they depend upon the species' life-history. Also, as discussed in Section 4.11 of Chapter 4, habitat linkages and fragmentation may be more critical for the sustainability of some populations.

As part of the Puget Sound Stormwater Management Research Program, Richter and Azous (2001c) found that the highest richness of small mammals was in wetlands with at least 60% of the first 1,640 feet (500 m) of buffer in forest cover. Other findings of this program include:

- The preservation of large woody debris within the wetland and adjacent upland forest is important for maintaining small-mammal habitat.
- Small-mammal richness was best associated with the combined factors of wetland size, adjacent forest, and the quantity of large, coarse woody debris within the wetland and its buffer.
- In southwestern Oregon, Cross (1985) conducted research on small mammals in "leave-strips" adjacent to streams within zones of forest that had been harvested. He found that the richness of small-mammal species was highest in the riparian zone closest to the stream, intermediate in the transition zone, and lowest in the upland zone. (The zones were defined by vegetation composition, not by dimension.) Because riparian habitats provide more niches for species, it is expected that such habitats would maintain greater species richness (Cross 1985).

Cross also found no species in the upland zone that were not found in the riparian zone, but he found five species present in the riparian zone that were not present in the upland or transition zones. A strip averaging 220 feet (67 m) wide supports mammal communities at similar numbers and richness to the nearby undisturbed riparian corridor. This study focused on small mammals which, relative to large mammals, have small home ranges. Therefore, the study is not broadly applicable to appropriate leave-strip dimensions for larger species.

Table 5-5 presents a summary of literature on wildlife and buffer/upland habitat use that was relevant to this synthesis. As noted previously, some of the research is specific to individual species, some is focused on a particular guild or group of similar species, some looks at life-history patterns (nesting distances), and other sources represent synthesis documents of buffer effectiveness. These distances do not necessarily reflect the literature relative to human disturbance and/or habitat fragmentation, which are discussed in the next sections.

It is difficult to synthesize the findings of the research on wildlife and the width of buffers into simple generalizations that can be readily applied. When looking at life-history needs (nesting sites, foraging ranges, etc.) the distances presented in the literature range from 98 feet (30 m) (Foster et al. 1984, Castelle et al. 1992) to 3,280 feet (1,000 m) (Richter 1997). These are distances measured in the field that species ranged, nested, or foraged from a wetland edge.

Other authors have presented their own synthesis or recommendations of effective buffer ranges based on review of the literature. These range from 49 feet (15 m) (Desbonnet et al. 1994) to 328 feet (100 m) (Groffman et al. 1991, Castelle et al. 1992, Desbonnet et al. 1994, McMillan 2000). Note that Desbonnet et al. (1994) recommend a range of buffer dimensions based on site conditions, species of interest, and proposed adjacent land uses; hence their studies are cited at both ends of the distance spectrum.

Table 5-5. Summary of studies on wildlife habitat provided by buffers.

Author(s)	Date	Width	Comments
Allen	1982	328 – 590 feet (100 – 180 m)	Mink use: generally concentrated within 330 feet (100 m) of water but will use upland habitats up to 590 feet (180 m) distant
Burke and Gibbons	1995	240 feet (73 m): 90% 902 feet (275 m): 100%	Buffer to encompass % nesting and hibernation of turtles in North Carolina
Castelle et al.	1992	197 – 295 feet (60 – 90 m): Western Washington 98 – 197 feet (30 – 60 m): Eastern Washington	Range for all species they noted. Range for all species they noted.
Castelle et al.	1992	263 feet (80 m) avg. - 590 feet (180 m)	Wood duck nesting locations from wetland edge (non-Washington data)
Castelle et al.	1992	98 feet (30 m): Eastern Washington 328 feet (100 m): Western Washington	Distance of beaver use of upland habitats from water edge
Chase et al.	1995	98 feet (30 m) or more	100 feet (30 m) would be “adequate”; buffers larger than 100 feet needed to meet habitat needs, including breeding for birds and some mammals
Cross	1985	220 feet (67 m)	Forested “leave-strips” for small mammal richness adjacent to streams in SW Oregon
Desbonnet et al.	1994	49 – 98 feet (15 – 30 m): low intensity 98 – 328 feet (30 – 100 m): high intensity	Variable buffer widths using adjacent land uses as decision-making criteria
Fischer et al.	2000	98 feet (30 m) minimum	Literature review; majority of literature cited recommends buffer widths of 330 feet (100 m) for reptiles, amphibians, birds, and mammals

Author(s)	Date	Width	Comments
Foster et al.	1984	98 feet (30 m): 68% of nests) 312 feet (95 m): 95% of nests	Waterfowl breeding use of wetlands in the Columbia Basin greatest in smaller (<1 acre [0.4 ha]) wetlands; 68% of waterfowl nests within 100 feet (30 m) of wetland edge; to encompass 95% of waterfowl nests would require 310 feet (95 m) of buffer
Groffman et al.	1991	197 - 328 feet (60 - 100 m)	For most wildlife needs
Groffman et al.	1991	328 feet (100 m)	Neotropical migratory bird species
Howard and Allen	1989	197 feet (60 m)	For most wildlife needs
McMillan	2000	98 – 328 feet (30 – 100 m)	Based on a synthesis of literature
Milligan	1985	49 feet (15 m)	Bird species diversity strongly correlated with the percentage of the wetland boundary buffered by at least 50 feet (15 m) of tree and shrub vegetation
Norman	1996	164 feet (50 m)	To protect wetland functions; more buffer may be required for "sensitive wildlife species"
Ostergaard	2001	3,280 feet (1,000 m)	Forested habitat surrounding stormwater ponds, related to native amphibian richness
Richter	1996	3,280 feet (1,000 m)	Literature review and synthesis
Richter	1996	3,280 feet (1,000 m)	Native amphibian use
Richter and Azous	2001b	1,680 feet (512 m)	Distance from wetland edge necessary to include all bird richness in Puget Sound lowland wetlands
Richter and Azous	2001c	1,640 feet (500 m): 60%	Highest small-mammal richness when 60% of first 1,640 feet (500 m) of buffer was forest habitat
Semlitsch	1998	1,969 feet (600 m)	Salamanders
Semlitsch	1998	228 – 411 feet (69.6 - 125.3 m) 539 feet (164.3 m) for 95% of all species	Six species of adult salamanders and two species of juveniles; mean distance from wetland edge was 228 feet (juveniles) – 411 feet (adults). To incorporate 95% of all species, buffer mean would have to be 539 feet
Short and Cooper	1985	164 – 328 feet (50 – 100 m)	164 feet (50 m) for foraging
Temple and Cary	1988	> 656 feet (200 m): 70% success 328 – 656 feet (100 – 200 m): 58% success < 328 feet (100 m): 18% success	Nesting success rates for interior-dwelling forest birds related to distance into the interior of a forest from the forest edge

5.5.4.2 Screening Adjacent Disturbances

Wetland buffers screen wildlife from human activities. Disturbance from humans can come in the form of noise and light (indirect effects) or from human presence/movement (direct effects). Noise and light can disrupt feeding, breeding, and sleeping habits of wildlife. Many wildlife species in wetlands are disturbed by unscreened human activity within 200 feet (61 m) (Washington Department of Wildlife in Castelle et al. 1992). Dense shrubs and trees in a wetland buffer can limit intrusion and screen out noise, light, and movement from adjacent human development (Castelle et al. 1992).

In addition, domestic pets such as dogs and cats can adversely affect wetland wildlife by preying on some wildlife species and are particularly damaging to ground-nesting species (Churcher 1989). See Section 4.12.5 in Chapter 4 for further discussion.

The effect of noise on wildlife is a topic of growing concern. Little research exists on the effective buffer widths required to filter sounds for wildlife. See Section 4.12.3 in Chapter 4 for a discussion of current literature on the effects of noise on wildlife.

Groffman et al. (1991) determined that 105 feet (32 m) of dense forested buffer was necessary to reduce noise from commercial areas to background noise levels. Shisler et al. (1987) differentiated between the impacts of low-intensity land uses (agricultural, recreational, low-density housing) and high-intensity land uses (high-density residential, commercial/industrial). They found that low-intensity land uses could be effectively screened with vegetated buffers of 49 to 98 feet (15 to 30 m), while high-intensity land uses required buffers of 98 to 164 feet (30 to 50 m).

Direct sighting of humans approaching was found to disrupt birds (change their behavior or cause flushing) between 46 and 164 feet (14 to 50 m) (Shisler 1987, Josselyn et al. 1989, Rodgers and Smith 1997). Looking specifically at great blue herons, Short and Cooper (1985) documented that they would flush from their nests if humans approached within 328 feet (100 m). Buffers between 46 and 164 feet (14 to 50 m) may be required to screen wildlife from direct observation of humans, while larger buffers (328 feet or 100 m) were documented as necessary to screen nesting herons.

Other researchers differentiated between the types of activities humans are engaged in and their effects on wildlife. Humans walking toward birds were studied to see how closely they could approach before birds flushed from perches or stopped foraging. In Florida, Rodgers and Smith (1997) found that humans could approach 46 to 112 feet (14 to 34 m) before flushing, but automobiles flushed birds at 61 to 78 feet (18.5 to 24 m). Interestingly they found that bird-watching (as opposed to humans who were simply walking) had the greatest adverse impacts on birds. They surmised this was due to the human behavior of stopping and standing with binoculars at one point for a prolonged time.

Cooke (in Castelle et al. 1992) analyzed 21 wetland sites in western Washington and concluded that buffers smaller than 50 feet (15 m) were generally ineffective in screening human disturbance from alterations such as noise, debris, and altered use of the buffer.

Table 5-6 summarizes the findings of the literature related to the disturbance limits or screening effects of a buffer for various wildlife species.

Table 5-6. Summary of studies on screening provided by buffers.

Author(s)	Date	Width	Comments
Castelle et al.	1992	200 feet (61 m)	General wildlife considerations
Cooke	1992	50 feet (15 m)	Analyzed 21 sites in King County. Buffers less than 50 feet were often disturbed by human activities and were not effective at screening "human effects". Cited in Castelle et al. (1992)
Groffman et al.	1991	105 feet (32 m)	Dense forest to filter sound from commercial land uses to natural background levels
Josselyn et al.	1989	49 – 164 feet (15 – 50 m)	Unscreened human activity within 50 – 164 feet was disruptive to waterbirds in San Francisco Bay area
Rodgers and Smith	1997	46 to 112 feet (14 –34 m) 61 to 78 feet (18.5 – 24 m)	Waterbirds in Florida: flushing distance from walkers 46 – 112 feet; flushing distance from autos 61 – 78 feet. Nature observation had greatest impact of human walking activities. Nesting birds tolerated closer human approach than birds that were perching/foraging
Shisler et al.	1987	50 - 100 feet (15 – 30 m) 100 – 164 feet (30 – 50 m)	Low-intensity land uses (agriculture, recreation, and low density residential): 50 - 100 feet High-density residential housing and commercial/industrial: 100 - 164 feet Most effective buffers had steep slopes, dense shrubs
Short and Cooper	1985	328 feet (100 m)	328 feet to buffer nesting great blue herons from human disturbance

5.5.4.3 Maintaining Habitat Connections

Increased isolation of wetlands and fragmentation of habitats result directly from human conversion of habitats to other uses. Buffers can play a role in reducing habitat fragmentation by serving as upland habitat directly adjacent to a wetland, or by providing an area that can connect or be part of a corridor that connects wetlands with upland habitats or other water bodies. Generally, buffers, as applied in a regulatory context, are rarely designed to provide these connections. Typical buffer widths generally are insufficient to link wetlands to other habitats. In addition, maintaining linkages from one habitat type to another on distinct parcels is often not a consideration when properties are reviewed case by case.

In general, the literature states that for terrestrial species with wide-ranging habits, connectivity between breeding, feeding, and refuge sites is critical for maintaining population viability. One may assume that this applies only to large terrestrial mammals. However, research has shown that many native amphibians on the west side of the Cascades can range 3,280 feet (1,000 m) from source wetlands into other wetlands or surrounding upland habitats (Richter 1997). Ostergaard (2001) found the greatest amphibian richness in sites that had upland forest habitat surrounding the site by 3,280 feet (1,000 m). Richter and Azous (2001b) found that a radius of 1,680 feet (512 m) surrounding a wetland was necessary to include all the bird richness of species utilizing the source wetland.

See Section 4.11 in Chapter 4 for further discussion of habitat connectivity and fragmentation.

5.5.4.4 Summary of Key Points

- There is no simple generalized answer for what constitutes an effective buffer width for wildlife considerations. The width of the buffer is dependent upon the species in question and its life-history needs, whether the goal is to maintain connectivity of habitats across a landscape, or whether one is simply trying to screen wildlife from human interactions.
- The majority of wildlife species in Washington use wetland habitats for some portion of their life-history needs. Many wetland-dependent species (those that depend upon wetlands for breeding, brood-raising, or feeding) depend upon surrounding upland habitats as well for some life-history stages.
- Many terrestrial species that are dependent upon wetlands have broad-ranging habits, some over 3,280 feet (1,000 m) from the source wetland. Although this might be expected for large mammals such as deer or black bears, it is also true for smaller species such as salamanders and other amphibians.
- Human access and land uses adjacent to wetlands influence the use and habits of wildlife through visual and auditory intrusions, as well as elimination or degradation of appropriate upland habitats. Even “passive” activities such as bird/nature-watching have been shown to have effects on roosting and foraging birds.
- Synthesis documents that evaluated many studies of wetland buffers for habitat protection recommend buffers widths of 50 to 300 feet (15 to 100 m) for most situations.

5.5.5 Buffer Maintenance and Effectiveness over Time

Buffers provide various functions to protect wetlands for as long as the buffers themselves remain intact. Buffer areas can be altered over time by human disturbance and natural events such as windstorms. In addition, some researchers have raised the issue of whether buffers have a long-term carrying capacity to improve water quality with regard to filtration and binding of pollutants.

5.5.5.1 Human Alteration to Buffers

Human activities are the most common mechanism for altering buffers over time. Buffer functions can be reduced if vegetation is cut or trampled, soils are compacted, sediment loading surpasses the filtering capability of the vegetation, or surface water flows create channels and subsequent erosion.

Cooke (in Castelle et al. 1992) analyzed 21 wetland sites in western Washington and concluded that buffers less than 50 feet (15 m) wide were more susceptible to being reduced over time by human disturbance. Nearly all of the buffers they studied that were less than 50 feet (15 m) in width were significantly reduced in the few years the buffers had been present on the back of private lots. Some of the buffers were found to have been eliminated through complete clearing of native vegetation. Of the buffers wider than 50 feet (15 m), most still had some portion intact and overall they showed fewer signs of human disturbance.

In a study in the Monterey Bay area of California, Dyste (1995) examined 15 wetlands with buffers. All of the buffers suffered from human alteration including cutting of vegetation, soil compaction, and dumping of garbage.

5.5.5.2 Loss of Trees to Blowdown

In the Pacific Northwest, forested buffers are often “created” as leave-strips around wetlands or along streams when the surrounding forest is cleared for land development. These forested strips are then exposed to winter windstorms, which are common, often resulting in substantial loss of large trees due to blowdown.

Pollock and Kennard (1998) concluded that trees in narrow forested buffers (less than 76 feet [23 m] wide) have a much higher probability of suffering significant mortality from windthrow and blowdown than trees in wider buffers. They conclude that buffers in the range of 76 to 115 feet (23 to 35 m), created when the surrounding forest is cut, are the minimum width that can be expected to withstand the effects of wind in the long term.

5.5.5.3 Reduced Capacity for Sediment/Nutrient Removal

Many of the studies described earlier assessed the effectiveness of buffers in removing sediments and nutrients for short durations (on the order of one to two years, if the time period was discernable in the methods sections of the literature). One study that assessed water quality improvement over longer periods found that effectiveness diminished as the outer margins of the buffers became saturated with sediment (Dillaha and Inamdar 1997). Their findings suggest that buffers have a limited carrying capacity for sediment removal and that larger buffers and other methods may be required to ensure long-term control of sediment.

Similarly, Todd (2000) cites work by Dillaha in 1993 that found less than 10% of grass filter strips were effective after three to five years. The grass filter strips became channelized and surface flows were no longer passing through as sheet flow that would allow contact with vegetation to remove sediments and nutrients. Todd emphasizes that, for buffers to be effective, they have to be sustainable over time and this must be a factor when determining buffer widths.

5.5.5.4 Summary of Key Points

- Human actions can reduce the effectiveness of buffers in the long term through removal of buffer vegetation, soil compaction, sediment loading, and dumping of garbage.
- Buffers may lose their effectiveness to disperse surface flows over time as flows create rills and channels, causing erosion within the buffer.
- Leaving narrow strips of trees can result in tree loss due to blowdown.
- Buffers may become saturated with sediment over time and become less effective at removing pollutants. The literature indicates that this should be considered when determining buffer widths.

5.5.6 Summary of Buffer Ranges and Characteristics from the Literature

The following discussion summarizes the many suggestions and recommendations in the literature for how buffer widths can be established. Many of these are found in synthesis documents that summarize scientific literature on buffers and then draw general conclusions. The recommendations in most of these syntheses take a more general approach and do not suggest how to determine buffer widths specifically in relation to desired functions such as protection of water quality or maintenance of habitat.

Several references (Castelle et al. 1992, Desbonnet 1994, Norman 1996, McMillan 2000, Todd 2000) identify four criteria that should be considered in determining the width of a buffer:

- The value of the aquatic resource to be protected by the buffer
- The characteristics of the aquatic resource in question, of the watershed contributing to the aquatic resource, and of the buffer itself
- The intensity of the adjacent land use (or proposed land use)

- The specific functions that the buffer is supposed to provide including the targeted species to be managed for and an understanding of their life-history needs

The feasibility or possibility of incorporating those four considerations into determining buffer dimensions is dependent upon the jurisdiction in question. Those same authors acknowledge that the scientific basis for determining the size of a buffer is often superseded by political expediency. Buffers are more often determined administratively as standard or fixed dimensions that may, or may not, be correlated with the criteria listed above.

Table 5-7 presents a summary of the buffer ranges recommended by the authors who conducted literature reviews or syntheses on buffer effectiveness. Minimums ranged from 25 feet (8 m) to 197 feet (60 m). Maximums ranged from 98 feet (30 m) for some land uses to 350 feet (107 m).

Table 5-7. Summary of recommendations for buffer dimensions from the literature.

Author(s)	Date	Minimum Buffer	Maximum Buffer	Comments
Castelle et al.	1994	25 feet (8 m)	98 feet (30 m)	"Adequate under most circumstances"
Desbonnet et al.	1994	49 feet (15 m)	98 feet (30 m)	Low-intensity land uses (agriculture, recreation, and low density residential)
		98 (30 m)	164 feet (50 m)	High-density residential housing and commercial/industrial
Fischer	2000	98 feet (30 m)	328 feet (100 m)	Larger buffer for reptiles, amphibians, birds and mammals
Groffman et al.	1991a	197 feet (60 m)	328 feet (100 m)	For most wildlife needs
Howard and Allen	1989	197 feet (60 m)		For most wildlife needs
McMillan	2000	25 feet (8 m)	350 feet (107 m)	Case by case, using a rating system and the intensity of proposed or existing land use
Norman	1996	164 feet (50 m)		To protect wetland functions; more may be required to protect more "sensitive wildlife species"

Table 5-8 outlines the general effectiveness of different buffer widths at removing pollutants and providing habitat (Desbonnet et al. 1994).

Table 5-8. A summary of pollutant removal effectiveness and wildlife habitat value of vegetated buffers according to buffer width (Desbonnet et al. 1994).

Buffer Width in Feet (m)	Pollutant Removal Effectiveness	Wildlife Habitat Value
16 feet (5 m)	Approximately 50% or greater sediment and pollutant removal	Poor habitat value; useful for temporary activities of wildlife
32 feet (10 m)	Approximately 60% or greater sediment and pollutant removal	Minimally protects stream habitat; poor habitat value; useful for temporary activities of wildlife
49 feet (15 m)	Greater than 60% sediment and pollutant removal	Minimal general wildlife and avian habitat value
66 feet (20 m)	Greater than 70% sediment and pollutant removal	Minimal wildlife habitat value; some value as avian habitat
98 feet (30 m)	Approximately 70% or greater sediment and pollutant removal	May have use as a wildlife travel corridor as well as general avian habitat
164 feet (50 m)	Approximately 75% or greater sediment and pollutant removal	Minimal general wildlife habitat value
246 feet (75 m)	Approximately 80% or greater sediment and pollutant removal	Fair to good general wildlife and avian habitat value
328 feet (100 m)	Approximately 80% or greater sediment and pollutant removal	Good general wildlife habitat value; may protect significant wildlife habitat
656 feet (200 m)	Approximately 90% or greater sediment and pollutant removal	Excellent general wildlife value; likely to support a diverse community
1,968 feet (600 m)	Approximately 99% or greater sediment and pollutant removal	Excellent general wildlife value; supports a diverse community; protection of significant species

Castelle et al. (1994), summarizing research conducted primarily before 1990, concluded "buffers necessary to protect wetlands and streams should be a minimum of 49 to 98 feet (15 to 30 m) in width under most circumstances." They note that the lower end of the spectrum is the minimum necessary to maintain physical and chemical processes, while the upper end of the spectrum may be necessary to maintain biological processes. This work appears to contradict the findings of Desbonnet et al. (1994). However, the language in the Castelle et al. report of 1994 states that the buffers should be a *minimum* of 49 to 98 feet; the report does not identify appropriate maximums. The report is most often quoted to imply that the full range of buffers should be *between* 49 and 98 feet.

McMillan (2000) recommends an approach to determining buffers that attempts to balance predictability with flexibility by setting standard buffer widths that can be altered on a case-by-case basis to adapt to site-specific factors. This approach for determining buffer width incorporates a rating system for wetlands, plus an assessment of the intensity of proposed or existing adjacent land use, to establish buffer widths ranging from 25 to 350 feet (8 to 107 m). It is perhaps the method that is closest to fitting the four bulleted criteria outlined at the beginning of this section. It incorporates an understanding of the condition of the wetland, the buffer, and the proposed adjacent land use.

Several other authors also suggest that considering site-specific factors enhances the effectiveness of buffer strips over using fixed-width buffers (Haupt 1959, Steinblums et al. 1984). Belt and O'Laughlin (1994) note that, "The fixed minimum-width approach enjoys the virtue of simplicity in application, but has the potential for providing either not enough or too much protection."

Liquori (2000) also cautions against using fixed buffer widths to protect long-term ecological functioning of buffers and their associated aquatic resources. He notes that many of the functions that buffers provide are directly related to physical characteristics and biological processes within the buffers, and therefore, informed by site-specific information, a case-by-case argument could be made for establishing buffer widths. "The nature of the [functions a buffer provides] may significantly depend upon riparian structure both locally and as a mosaic over the watershed scale."

In urban settings, larger buffer widths are often prescribed in anticipation of future impacts from adjacent land use and activity upstream in the watershed. The most important criterion for determining buffer width is identification of the various functions the buffer is expected to provide. (Todd 2000.)

In agricultural lands, Welsch (1991) identifies a three-zone approach for establishing buffers:

- **Zone 1** consists of riparian-type trees and shrubs immediately adjacent to the stream, water body, or wetland. It should be a minimum 13 feet (4 m) wide, or adjusted to include the entire riparian area (the area with year-long or seasonal soil-moisture regime influenced by the stream or water body). Minimum length should be the length of the proposed disturbance outside the riparian management zones, or "the longest distance possible."

- **Zone 2** extends upslope from Zone 1 and consists of vegetation that may be periodically harvested as it matures. A minimum distance of 20 feet (6 m) should be allowed for this zone for small streams or water bodies; for larger streams or water bodies the total of Zones 1 and 2 can be increased up to 98 feet (30 m) or 30% of the geomorphic floodplain (whichever is less). Minimum length should match that of Zone 1. Zone 2 can be an active harvest zone, but trees and vegetation need to be left to provide soil holding and filtering capacity.

- **Zone 3** is added upslope of Zone 2 if adjacent land (away from the aquatic resource) is cultivated cropland or another land use with the potential for erosion or sediment production. Zone 3 is a vegetated filter strip and should be wide enough to control "concentrated flow erosion from cultivated cropland." Zone 3 vegetation should be established prior to the establishment of Zones 1 and 2.

This zonal approach is in response to proposed land use of active agriculture which implies regular creation of conditions with high erosion potential (grazing or tilling). It also allows more active use of the central portion of the buffer and active management of the outer area of the buffer.

Townsend and Robinson (2001) build on this zonal approach and recommend guidance on maintenance of canopy coverage and closure. They suggest using species that readily resprout from stumps or roots in the areas nearest the stream channels (to allow the vegetation to respond to flood damage and/or beaver activity). They stress the need for ongoing maintenance, especially in Zone 3, to ensure that erosive flows are not causing rills or channelized flows into Zone 2. They also note that while most of these buffers will be applied on an ownership basis, greater benefit would be realized if the concept of zoned buffers were applied on a watershed basis.

Other recommendations are based on wildlife species of particular interest. Based on their study of waterbirds in Florida, Rodgers and Smith (1997) recommend a buffer width of 328 feet (100 m) to ensure that birds will not be triggered into an "approach" response, a state which occurs prior to actual flushing. They derived this figure by analyzing the flushing distance from human approach for 16 species, then adding 131 feet (40 m) to that distance. The 131-foot (40 m) distance was derived from previous work which found that birds became alert (stopped their ongoing behavior and focused on the approaching human) in a range of 82 to 131 feet (25 to 40 m).

5.5.6.1 Summary of Key Points

- Several researchers have recommended using four basic criteria to determine the width of a buffer:
  - the value of the aquatic resource to be protected by the buffer;
  - the characteristics of the aquatic resource in question, of the watershed contributing to the aquatic resource, and of the buffer itself;
  - the intensity of the adjacent land use (or proposed land use); and
  - the specific functions that the buffer is supposed to provide including the targeted species to be managed for and an understanding of their life-history needs.
- Protecting wildlife habitat functions of wetlands generally requires larger buffers than protecting water quality functions of wetlands.
- Effective buffer widths should be based on the above factors and generally should range from: 25 to 75 feet (8 to 23 m) for wetlands with minimal habitat functions and adjacent low-intensity land uses; 50 to 150 feet (15 to 46 m) for wetlands with moderate habitat functions or adjacent high-intensity land uses; and 150 to 300 feet (46 to 92 m) for wetlands with high habitat functions.
- Fixed-width buffers may not adequately address the issues of habitat fragmentation and population dynamics. Several researchers have recommended

a more flexible approach that allows buffer widths to be varied depending on site-specific conditions.

5.6 Chapter Summary and Conclusions

Wetlands are defined using well established language that is generally consistent between federal and state laws. However, certain wetland types are sometimes excluded from regulation. These include small wetlands, isolated wetlands, and Prior Converted wetlands. The scientific literature makes clear that small wetlands and isolated wetlands provide important functions and does not provide any rationale for excluding these wetlands from regulation. Little scientific information is available on Prior Converted wetlands, but there is no evidence to suggest that they are unimportant in providing wetland functions.

Wetland delineation is conducted according to either the federal or state delineation manual. These manuals are consistent and, when applied correctly, will result in the same wetland boundary. Wetland rating systems are a useful tool for grouping wetlands based on their needs for protection. The most widely used method in Washington is the state's rating system which places wetlands in categories based on their rarity, sensitivity, irreplaceability, and functions.

Wetland buffers are a critical tool for protecting wetland functions. Findings regarding buffer functions and effectiveness are related to what functions are in question, what land use activities are being buffered, and the characteristics of the wetland and the buffer itself.

The literature confirms that for water quality improvement (e.g., sediment removal and nutrient uptake) there is a non-linear relationship between buffer width and increased effectiveness. Sediment removal and nutrient uptake are provided at the greatest rates within the immediate outer portions of a buffer (nearest the source of sediment/nutrient), with increasingly larger widths of buffers required to obtain measurable increases in those functions. Additionally, the long-term effectiveness of buffers in providing such mechanical and biological processes is not well documented in the literature and may represent a critical need for future research.

For buffer functions related to protection of wildlife species and populations that use wetlands, the literature has documented the need for significantly larger buffers than those adequate to provide sediment removal and nutrient uptake. Research confirms that many wildlife species and guilds are dependent upon wetlands for only portions of their life cycles and they require upland habitats adjacent to the wetland to meet all their life needs. Some species use upland habitats that are far from the source wetland. The literature documents that, without access to appropriate upland habitat and the opportunity to move between habitats across a landscape, it is not possible to maintain viable populations of many species. Beyond simply providing adequate upland habitat adjacent to a single wetland, the literature on the maintenance of wildlife populations finds that it is necessary to link habitat types, including wetlands and uplands, across a landscape in order to maintain genetically viable populations.

Several authors who suggested recommendations for buffer widths based on their own synthesis of the literature have recommended variable widths based on the conditions of the wetland, the conditions of the buffer, the proposed land uses adjacent to the buffer, and what functions are intended to be managed. For protection and maintenance of wildlife habitat functions of wetlands, these studies suggest that effective buffer widths should be based on the above factors and generally should range from: 25 to 75 feet (8 to 23 m) for wetlands with minimal habitat functions and adjacent to low-intensity land uses; 50 to 150 feet (15 to 46 m) for wetlands with moderate habitat functions or high-intensity land use that is adjacent; and 150 to 300 feet (46 to 92 m) for wetlands with high habitat functions.

Chapter 6 continues the discussion of regulatory tools used to manage wetlands by discussing wetland compensatory mitigation and its effectiveness.